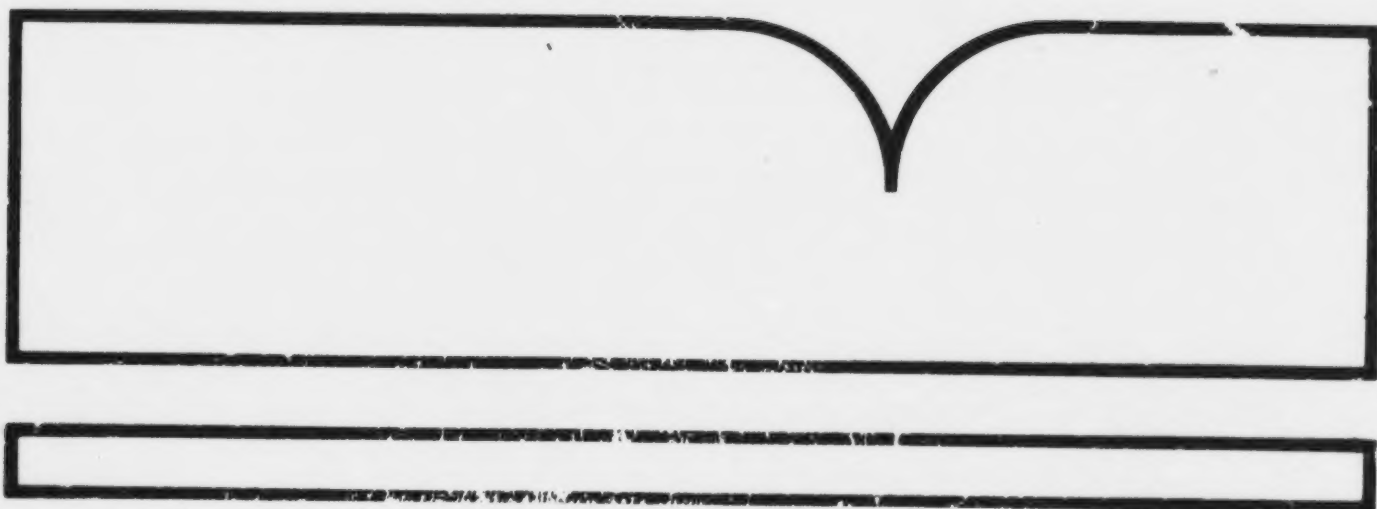


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Comparison of Innovative Technology for
Thermal Destruction of Hazardous Waste

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A COMPARISON OF INNOVATIVE TECHNOLOGY FOR
THERMAL DESTRUCTION OF HAZARDOUS WASTE

by

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16. ABSTRACT This paper briefly summaries and compares six technologies which are considered to be innovative to the thermal destruction of hazardous wastes. The six technologies are: Fluidized Bed, Molten Salt, High Temperature Fluid Wall, Plasma Arc, Wet Air Oxidation and Supercritical Water. This paper concludes that: 1. Tests of a few technologies have shown that the selected waste can be destroyed to meet the 99.99% DRE requirement. 2. Wet Air Oxidation apparently has the lowest temperature and the longest residence time requirement. 3. Plasma has the highest temperature characteristic. 4. Supercritical water has the highest pressure requirement.		
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A Comparison of Innovative Technology
for Thermal Destruction of Hazardous Waste

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INTRODUCTION

It was estimated that 57 million tons of organic hazardous wastes are generated annually in the United States, and 90 percent of them is disposed of by environmentally unsound methods, thus posing a serious threat to human health and the environment.¹ The Federal government responded to the critical hazardous waste problem with the enactment of the Resource Conservation and Recovery Act (RCRA) in 1976, and a comprehensive "Superfund" program in 1980 to assure a reliable management of hazardous waste disposal and dump site clean-up. Successful implementation of both RCRA and the Superfund legislation requires major research and development efforts including developing innovative technologies to dispose of hazardous waste effectively.

Current estimates indicate that approximately 40 percent¹ of the hazardous waste can be disposed of by using thermal destruction technologies. Thermal treatment processes include many technologies that have in common the use of either direct or indirect heat to break chemical structures of organic compounds, thus reducing the volume and toxicity of the remaining residuals. Although incineration is probably the most widely known and used thermal process, there are many other thermal processes that are substantially different from incineration. Among these are pyrolysis; in which the material is heated in an oxygen-deficient environment; wet air oxidation, in which organic materials suspended in water are oxidized in a pressurized reactor; cogeneration, in which the material to be destroyed is used as a fuel in a boiler or industrial process and burned directly with the primary fuel; and molten salt destruction, in which material is injected beneath a bed of molten salt.

Thermal treatment processes generally can, in a matter of seconds or minutes, virtually destroy or significantly reduce what might otherwise take months or years to degrade in a landfill, eliminate certain health and environmental hazards associated with landfill disposal, reduce the need for new landfill capacity, prevent contamination of groundwater supplies, and eliminate problems from resurfacing in the future. A study of the current existing incinerator profile² shows that three types of conventional incineration processes dominate the incineration field. They are the liquid injection, rotary kiln, and hearth processes. A summary of their features, along with those of some others, is given in Table 1.

TABLE 1. CONVENTIONAL INCINERATORS

INCINERATOR TYPE	POPULATION UNITS	PERCENT	COMBUSTION ZONE TEMPERATURE, OF	COMBUSTION GAS RESIDENCE TIME, SECONDS	EXCESS AIR, % STOICHIOMETRIC
LIQUID INJECTION	213a	60.5	1800-3000	0.3-2.0	25-150
ROTARY KILN	17b,c	4.8	1200-2300	2 HR (SOLIDS)	50-250
AFTERBURNER			2000-2500	1.0-3.0	120-200
HEARTH	75b	21.3			
PRIMARY CHAMBER			1200-1800	--	30-200
SECONDARY CHAMBER			1400-2200	1.5-2.5	200-400
FLUIDIZED BED	5	1.4	1000-1400	1.0-5.0	100-200
OTHERS	42a	11.9			

(a) INCLUDES FUME/LIQUID UNITS

(b) INCLUDES UNITS BOTH WITH AND WITHOUT LIQUID INJECTION

(c) INCLUDES 2 ROTARY KILNS IN COMBINATION UNITS

(d) INCLUDES 3 COMBINATION UNITS NOT HAVING A ROTARY KILN

One of EPA's incineration research activities is to assist private industry in developing innovative technologies either to dispose of the waste in a more cost-effective manner or to dispose of the waste which conventional incineration technologies cannot handle. In recent moves, EPA sponsored Rockwell International Corporation to test its pilot-scale molten salt reactor in 1981, and developed two separate cooperative agreements with New York State and the State of California in 1982. The purpose is to perform pilot- or full-scale testing of various technologies (not technology development per se) which are considered to be innovative approaches to hazardous material destruction. Technologies to be tested include plasma arc, high-temperature fluid wall, and wet air oxidation. Technologies under consideration for EPA in-house research include supercritical fluid (to be tested at IERL-Cincinnati) and fluidized bed (to be tested at IERL-RTP) (IERL being the acronym for the Industrial Environmental Research Laboratories). One important criterion of selecting these technologies is that they are at least at the stage of pilot-scale development and appear to be promising.

This paper compares relative merits of the above selected six technologies. Specifically, it covers: (1) description of technology, (2) technology advantages and disadvantages, (3) representative compounds for testing selection and recommendations, and (4) data comparison among the six technologies.

TECHNOLOGY DESCRIPTION

For a quick reference purpose, the six selected technologies to be discussed are summarized as follows:

<u>Technology</u>	<u>Major Difference</u>	<u>Process Pattern</u>
1. Fluidized Bed	Bed materials are sands or limestone powders	Low temperature incineration coupled with simultaneous scrubbing of products by bed materials.
2. Molten salt	Bed materials are molten carbonate salts.	Same
3. High temperature fluid wall	Infrared radiative heat at 2200°C	High temperature pyrolysis
4. Plasma Arc	Ultraviolet radiative heat at 50,000°K	Same
5. Wet Air Oxidation	Oxidation occurs in a saturated zone	Multi-phase oxidation
6. Supercritical water	Oxidation occurs in a supercritical zone	Same

1. Fluidized Bed Combustion (FBC)

Process Description

FBC has been used for coal combustion and municipal sludge incineration for the last 10 years. Because of its special character, simultaneous combustion and scrubbing in the bed, FBC has recently been investigated for possible hazardous waste disposal. In general, a FBC incinerator is not significantly different from that of burning coal or municipal sludge. Its major components include a plenum chamber (or windbox), an orifice plate (or air distributor), and a bed (or combustion zone). The bed is usually composed of either inert materials (such as sand), or limestone, depending upon the particular application. A generalized flow diagram is shown in Figure 1.

During operation, a chemical waste, along with fuel oil if necessary, is injected into a fluidized bed combustor operating at approximately 750°C. Air is forced up through the bed material at such a velocity that the mixture behaves like a boiling liquid, and limestone is continuously added to the bed to replenish that expended by reaction with combustion products. Also during operation, bed material is periodically drained from the vessel to maintain the appropriate bed depth and fluidity.

Case Study³

Incineration tests of selected chemical wastes were conducted at the fluidized bed incinerator facility operated by Black Clawson Fibreclaim, Inc., in Franklin, Ohio. These tests were performed under the contract with Systems Technology Corporation to determine the effectiveness of thermal destruction of two different industrial liquid wastes: (1) an aqueous phenolic sludge, and (2) an aqueous solution of methyl methacrylate monomer. Each waste was burned at two different conditions to determine the effects of normal operating and equipment variables. The testing results are shown in Table 2.

Technology Advantages

- a. Because of intimate contact with heated particles, wastes are combusted at lower temperatures than that of conventional incinerators.
- b. Temperatures in the vessel are high enough to destroy wastes, but low enough to prevent formation of NO_x.
- c. The bed material acts as a scrubber to capture acid gas from the process, creating a non-toxic solid residue.

Technology Disadvantages

- a. Removal of inert residual materials from the bed is a potential problem area. As waste combustion proceeds, non-combustible ash

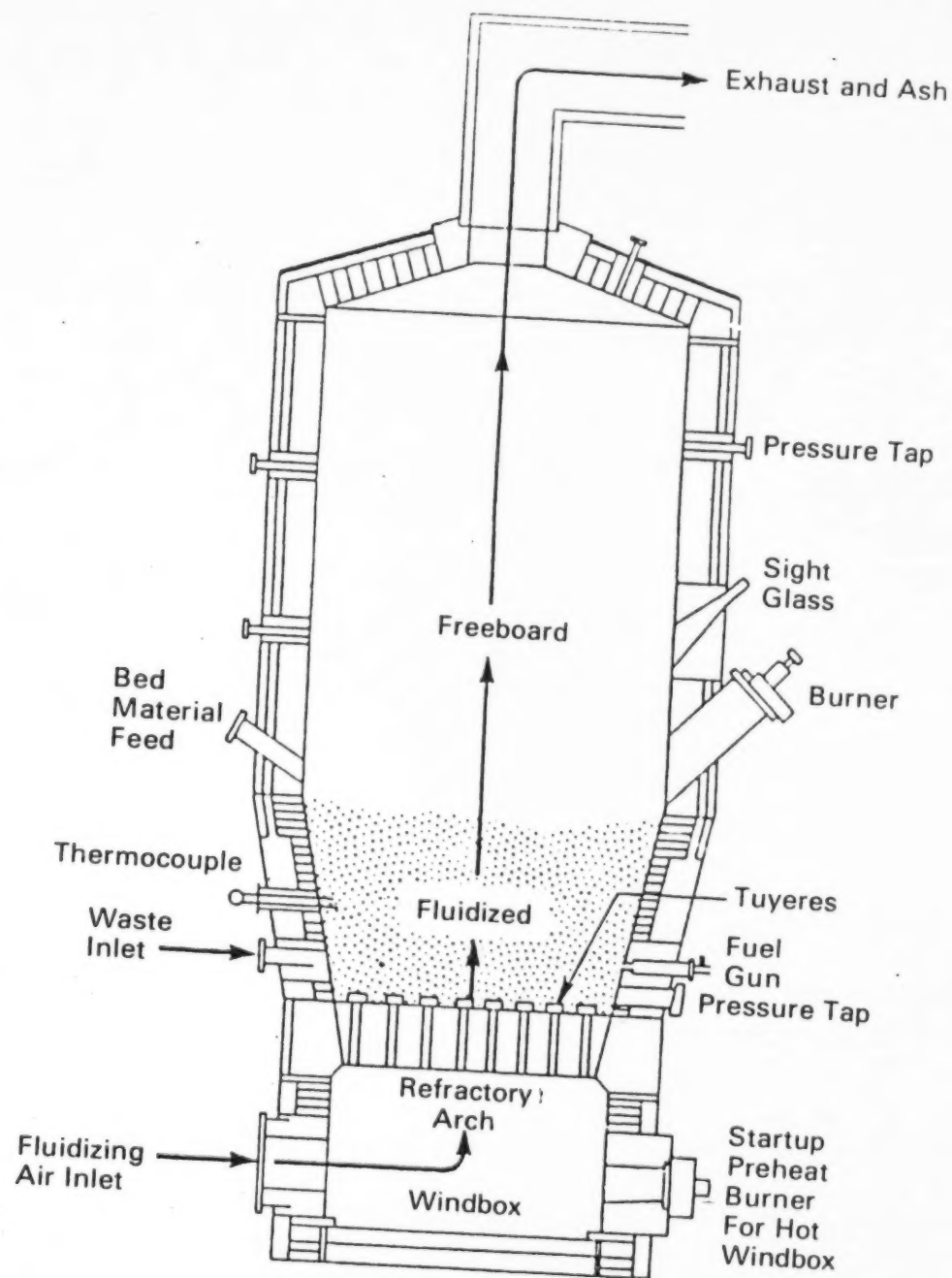


FIGURE 1. A CROSS SECTION OF A FLUIDIZED BED INCINERATOR

TABLE 2. TESTING RESULTS OF FBC

	PHENOL WASTE	METHYL METHACRYLATE
BED TEMPERATURE, AVERAGE (°C)	740-757	774-788
FREEBOARD TEMPERATURE (°C)	813-899	824-843
RESIDENCE TIME (SEC)	12-14	12
WASTE FEED RATE (L/MIN)	34-50	30-36
WASTE-TO-AUXILIARY FUEL* (L/L)	2.3-3.0	2.0-2.6
QUALITY OF STACK EMISSIONS		
PARTICULATE (MG/M ³)	1280-1430	560-630
TRACE METALS (MG/M ³)	0.44-0.87 Pb	0.55-2.2 Pb
QUALITY OF COMBUSTION GAS (BEFORE SCRUBBING):		
TOTAL ORGANICS (MG/M ³)	7.0-7.6	7.5
WASTE CONTENT (MG/M ³)	NOT DETECTED (<0.03)	NOT DETECTED (<0.16)
TRACE METALS (MG/M ³)	1.0-1.2 Pb	0.85-4.7 Pb
QUALITY OF SCRUBBER WATER:		
TOTAL ORGANICS (MG/L)	NOT DETECTED (<0.4)	NOT DETECTED (<0.2)
TRACE METALS (MG/L)	0.50-2.7 Pb	0.45-1.8 Pb
QUALITY OF ASH (FLUIDIZING SAND):		
WASTE CONTENT (MG/KG ASH)	NOT DETECTED (<0.2)	NOT DETECTED (<1.0)
DESTRUCTION EFFICIENCY:		
TOTAL ORGANICS (PERCENT)	99.97-99.98	99.99
WASTE CONSTITUENTS (PERCENT)	>99.999	>99.999

*NL 2 OIL UTILIZED AS AUXILIARY FUEL FOR ALL TESTS

accumulates in the bed. Beds with higher than 20 wt% ash are undesirable since at ash levels of this magnitude, defluidization can occur.

- b. Relatively large amounts of particulate matter entrained in the exhaust gases require elaborate pollution control devices.
- c. Waste feed particle size must be controlled to maintain a uniform feed rate.
- d. Accurate control is needed to ensure that retention time in the bed is sufficient for complete combustion, and that radical increases in a waste's heat value will not drastically boost bed temperatures and adversely affect bed operation.
- e. Sophisticated analytical methodology for the analysis of hazardous residues in the spent bed materials is required. The analysis is required to determine how much unburned waste remains in the residues and to examine how much waste residue is leachable to the environment. It is quite possible that milligram amounts of hazardous materials may remain in the spent bed materials undetected. Disposal of the spent materials would then recycle the hazardous material back into the environment. This situation would be especially dangerous in the case of chemical warfare agents.
- f. Other problems include corrosion of the combustor and mechanical devices for feeding wastes to the combustor, and the disposing of ash from the combustor.

2. Molten Salt Combustion (MSC)

Process Description

MSC has long been used in the metallurgical industry to recover metals, especially aluminum. Recently, extensive research has been conducted on possible applications of the technology to organic waste destruction, coal gasification and flue gas desulfurization.

Greenberg^{4,5} developed much of the theoretical basis for molten salt combustion of hazardous waste. He also made an extensive survey of salt combinations which can be used in the process. The salts used in the process should be stable at temperatures required for combustion of specific hazardous substances.

Since beginning the development of MSC technology in 1969, Rockwell International Corporation has constructed four units of varying sizes. Two of these units are bench-scale combustors with feed rates of 0.25 - 1.0 kg/h. They are used for feasibility and optimization studies. A pilot-plant unit has a feed rate of 15-100 kg/h. The fourth combustor is portable and is used for disposal of empty pesticide containers⁶. All tests were successful in that the objectives of achieving the required extent of destruction were met.

Molten salt destruction is a method of combusting organic material while, at the same time, scrubbing, in-situ objectionable by-products of the combustion and thus preventing their emission in the effluent gas stream. This process of simultaneous combustion and scrubbing is accomplished by injecting the material to be burned with air, or oxygen-enriched air, under the surface of a pool of molten carbonate salts. The melt is maintained at temperatures on the order of 1650°F (900°C) to promote rapid oxidation of organic waste. Halogen species in the waste form halide salts and phosphorus, sulfur, arsenic or silicon (from glass or ash in the waste) form the oxygenated salts such as sodium phosphate, sulfate, arsenate or silicate, respectively. These products are retained in the melt as inorganic salts rather than released to the atmosphere as volatile gases.

Case Study⁶

Rockwell has conducted many tests during the development of their molten salt reactor. Table 3 shows their typical bench-scale data on the destruction of hazardous waste.

In 1981, under their contract with EPA, Rockwell tested hexachlorobenzene and chlordane in their pilot-scale molten salt reactor. The results show that the destruction and removal efficiency of the Reactor exceeds 99.99% for these chemicals.

Technology Advantages and Disadvantages

In general, MSC has the same advantages and disadvantages as stated for FBC. However, MSC may not be applicable to dilute acidic-type wastes because rapid contact between water and salt melt may result in explosion.

3. High Temperature Fluid Wall (HTFW)⁷

Process Description

Thagard Research Corporation began to develop their HTFW reactor in the early 1970's. The reactor was originally designed for the continuous dissociation of methane into carbon black and hydrogen. The process requires the generation of stable temperatures above 1600°C and the prevention of precipitate formation on the reactor wall.

The key within the reactor is to keep the reacting stream out of physical contact with the reactor wall by using a gaseous blanket to keep them separated. The gaseous blanket is formed by flowing an inert gas radially inward through a porous reactor tube (a core). The inert gas is also used as heat transfer media to carry high rates of heat to accomplish the heating of the porous carbon core to incandescence so that the predominant mode of heat transfer is by radiation from the core to the stream. By avoiding physical contact of the stream with the core, the problem of chemical compatibility of the two (stream and core) becomes a non-problem. Additionally, the heating of particles was accomplished without the necessity of bringing the entire system to the same temperature.

TABLE 3. ROCKWELL'S TESTING DATA

TYPE OF WASTE	WASTE	TEMPER- ATURE (°C)	CONCENTRATION OF UNREACTED WASTE IN OFF GAS (MG/M ³)	CONCENTRATION OF UNREACTED WASTE IN MELT (WPPM)	DESTRUCTION EFFICIENCY (%)
CHEMICAL	PCB	750-900	0.5	0.08	99.9994
	PERCHLOROETHYLENE BOTTOMS	850-950	ND*	NA**	
	CHLOROFORM	818	ND	ND <0.1	>99.999
	TRICHLOROETHANE	840	ND	NA	>99.999
	DIPHENYLAMINE HCL	922	ND	ND <0.1	>99.999
	NITROETHANE	892	ND	ND <1	>99.993
	AQUEOUS SLURRY OF TBP	939	0.1	NA	>99.99
	PARA-ARSANILIC ACID	924	ND	ND <0.1	>99.999
PESTICIDES	DDT POWDER	900	0.3	ND <0.05	99.998
	MALATHION	900	0.06	ND <0.01	99.9998
CHEMICAL	VX	930	ND	ND <0.00003	>99.99999
WARFARE	GB	925	ND	ND <0.0003	>99.999999
AGENTS	MUSTARD	925	ND	ND <0.1	>99.999999
			ND <0.03	ND <0.03	>99.99998

*ND = NOT DETERMINED

**NA = NOT ANALYZED

While successfully pyrolyzing methane to carbon and hydrogen at rates of commercial interest, the reactor also demonstrates its usefulness in other applications including the pyrolysis of organic material to carbon and hydrogen or to carbon, carbon monoxide and hydrogen (depending on the composition of the starting material), and the production of high-melting-point refractories and portland cement.

A partial horizontal cross-section of a typical Thagard Reactor is shown in Figure 2, and a vertical cross-section is shown in Figure 3. The reactor is heated electrically with the six carbon resistance heaters. Because of the extreme temperatures encountered in operation of the device, the insulation package consists not of refractory brick but of a radiation shield made of multiple layers of graphite paper backed up with carbon felt.

During operation, the waste material to be pyrolyzed is finely ground to a 20 mesh and introduced into the top of the reactor. As the material falls through the tubular space it is exposed through radiative coupling to power densities of over 1200 watts/in². The finely-divided reactants are heated through the direct impingement of electromagnetic radiation. Examples of reactions are shown in Table 4.

The theoretical basis of the reactor is based on the following radiative heat transfer equations.

$$P = \sigma \epsilon T^4, \text{ where}$$

P = black body radiative power radiated per unit area, watts $\cdot$ cm⁻²

σ = Stefan-Boltzmann constant, $5.3 \cdot 10^{-13}$ watts $\cdot$ cm⁻² $\cdot$ $^{\circ}\text{K}^{-4}$

ϵ = emissivity of the substance, $0 < \epsilon < 1$

T = absolute temperature of the substance, $^{\circ}\text{K}$

This function is plotted in Figure 4. Inspection of Figure 4 shows that radiation as a heat transfer method does not become significant until temperatures on the order of 1650 $^{\circ}\text{C}$ are reached.

This emitted spectrum of the blackbody radiator changes, of course, with temperature. Figure 5 shows the relative spectral distribution of blackbody radiators for several different temperatures. Inspection of the curves shows that if the temperature is greater than 2000 $^{\circ}\text{K}$, most of the radiation is in the near infrared.

In the near infrared, many materials exhibit very strong absorption coefficients: coal, for example, has an absorption coefficient on the order of 10^5 cm⁻¹ which means (to a first approximation) that most of the incident energy is absorbed in a surface layer on the order of 10^{-5} cm thick.

TABLE 4. HTFW REACTION PATTERN

<u>FEEDSTOCK</u>	<u>EXAMPLE REACTION</u>	<u>PRODUCT</u>
Hydrocarbon, Oil or Gas	$\text{CH}_4 \rightarrow \text{C} + 2\text{H}_2$	Carbon Black
Chlorinated Hydrocarbons	$\text{C}_6\text{Cl}_6 + 3\text{Ca}(\text{OH})_2 \rightarrow 3\text{CaCl}_2 + 6\text{CO} + 3\text{H}_2$	Inert material
Hydrocarbon Oil Emulsion Coal/water Slurries	Hydrocarbon + $\text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2$	Synthesis gas
High Sulfur Oil Synthesis Gas	$\text{Oil} + \text{Ca}(\text{OH})_2 + \text{Air} + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2 + \text{CaS}$	Sulfur-free syngas
High Sulfur Oil	$\text{Oil} + \text{Ca}(\text{OH})_2 + \text{Air} + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2 + \text{CaS}$	Sulfur-free syngas
Calcium Carbonate and Silica	$\text{CaCO}_3 + \text{SiO}_2 \rightarrow \text{Cement}$	Cement
Coal & Calcium Hydroxide	$\text{Coal} + \text{Ca}(\text{OH})_2 \rightarrow \text{CaC}_2 + \text{CO} + \text{H}_2$	Calcium Carbide
Nuclear Waste	$\text{Waste} + \text{Ca}(\text{OH})_2 + \text{Clay} \rightarrow \text{Glass}$	Inert glass beads

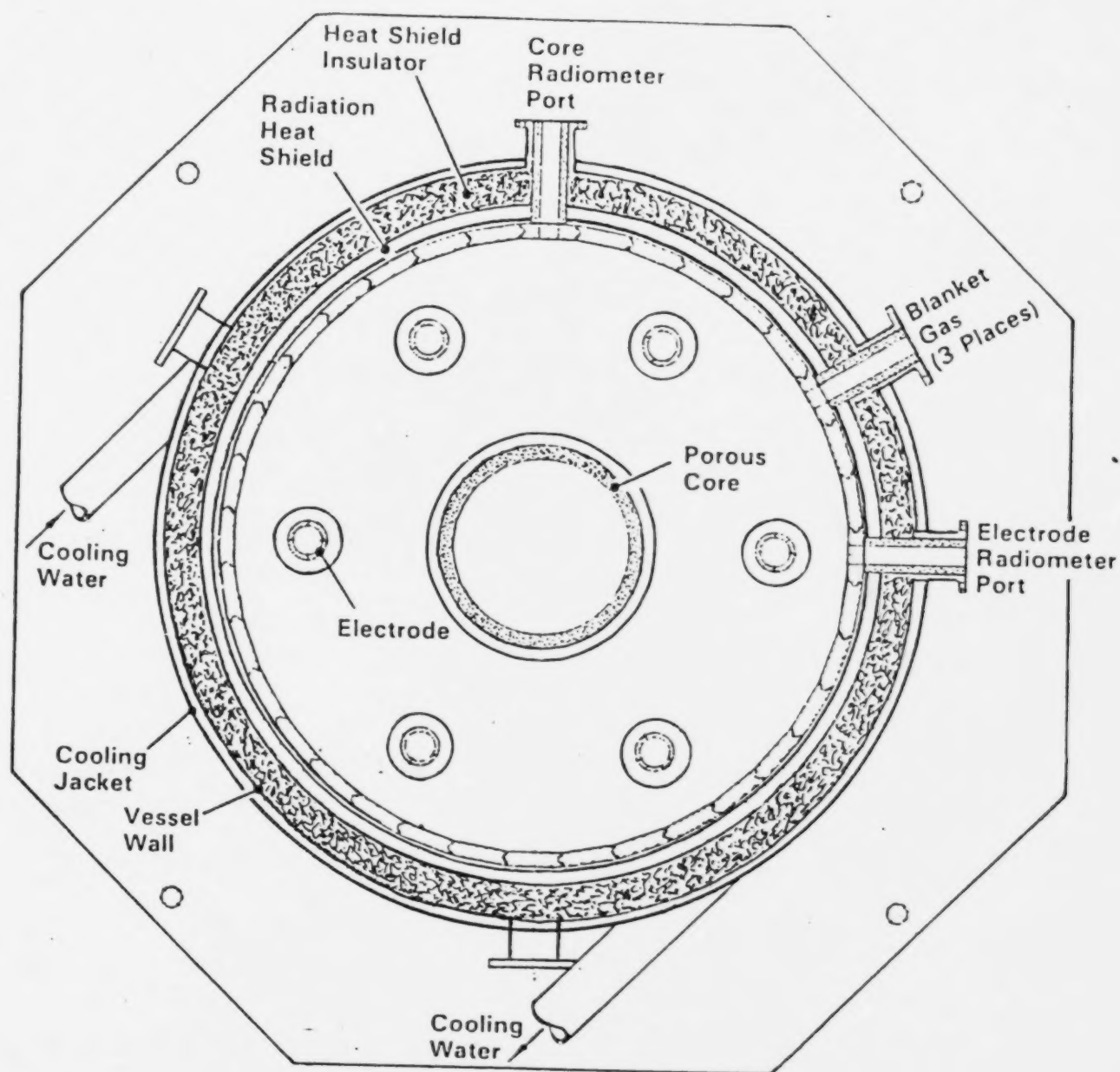


FIGURE 2. HORIZONTAL CROSS SECTION OF A
TYPICAL FLUID-WALL REACTOR

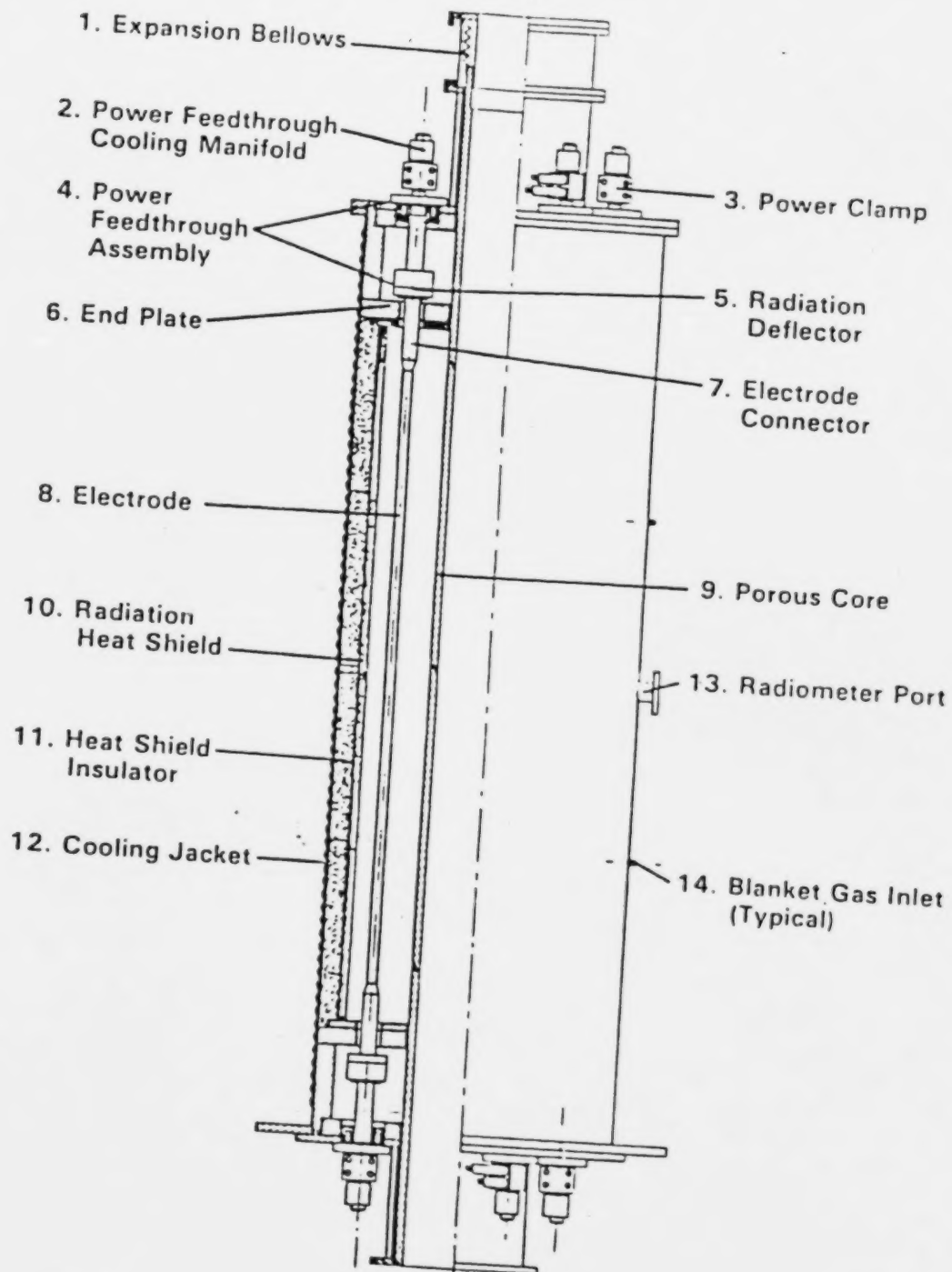


FIGURE 3. VERTICAL CROSS SECTION OF A
TYPICAL FLUID-WALL REACTOR

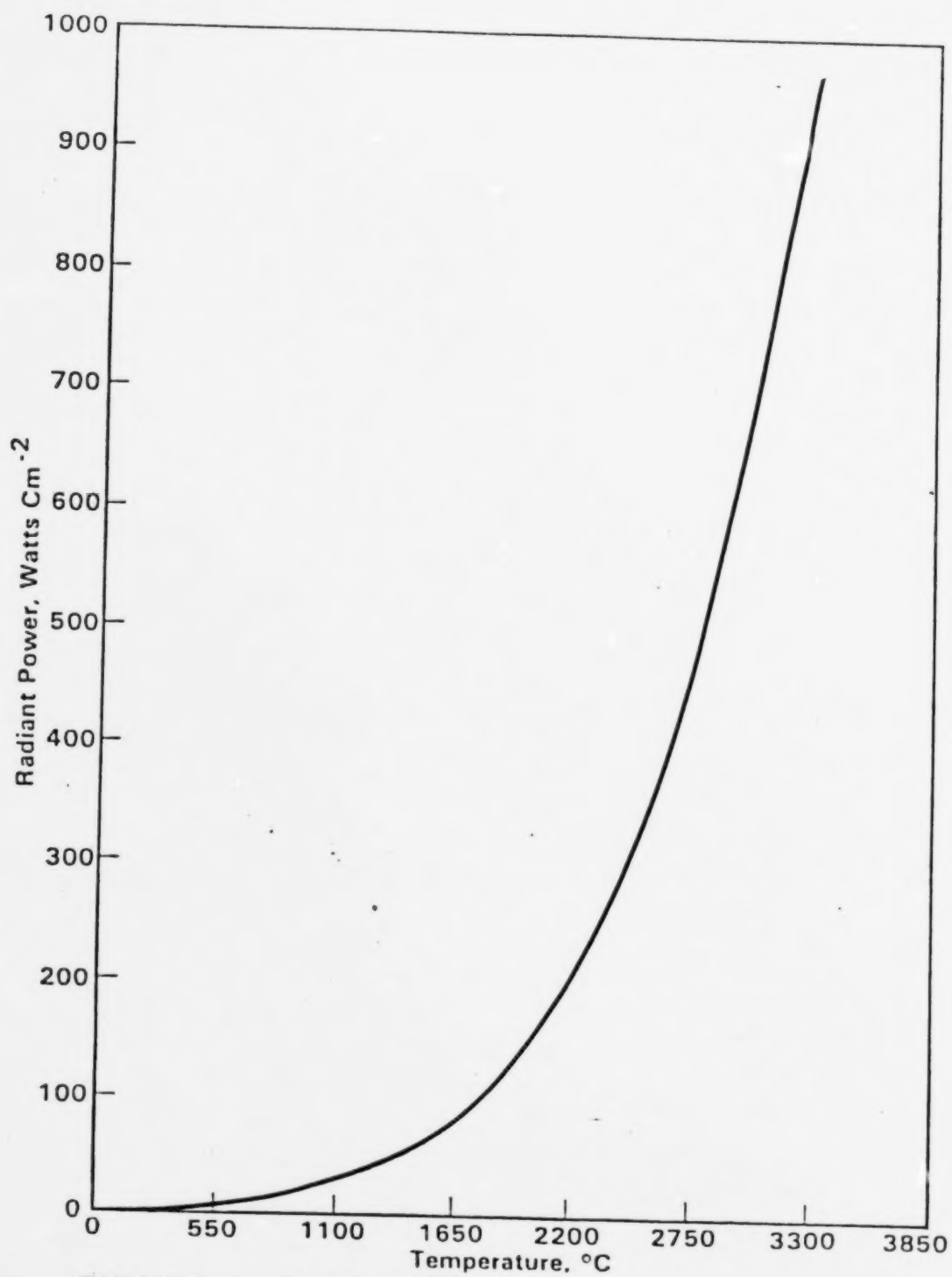


FIGURE 4. BLACKBODY RADIANT EMISSION
VS. TEMPERATURE

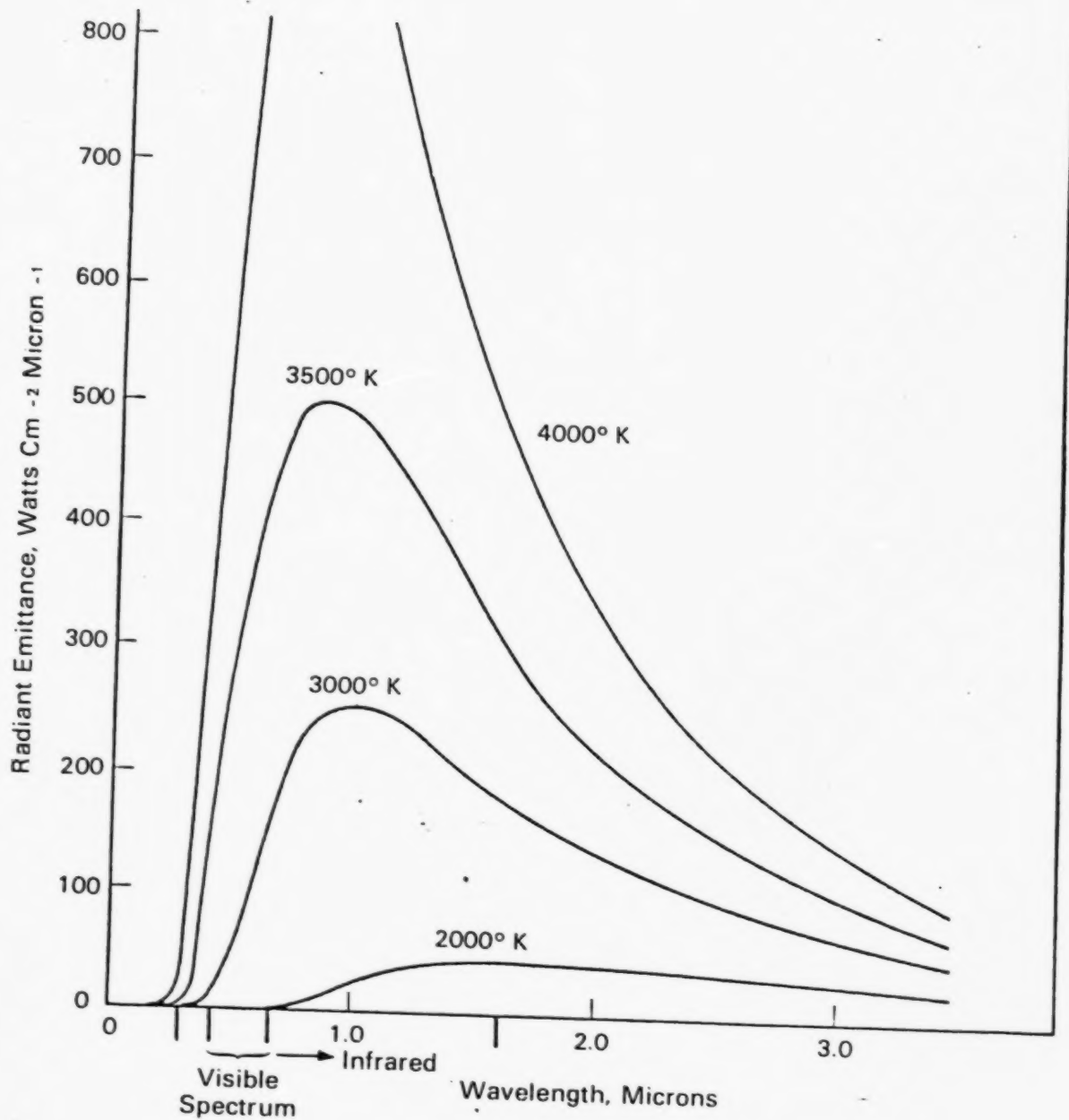


FIGURE 5. SPECTRAL OUTPUT OF BLACKBODY RADIATORS AT VARIOUS TEMPERATURES

The rate of temperature rise on the surface of a coal particle can be estimated by the equation

$$\frac{T}{t} = \frac{P}{MC} \quad \text{and} \quad M = \frac{\rho}{\alpha}$$

where

- T = temperature rise
- t = unit time
- P = radiative power
- c = specific heat
- M = mass
- ρ = density
- α = absorption coefficient

At 2200°C, the blackbody radiative power density is on the order of 200 watt/cm². The specific heat of coal is 0.5 Joule/g °F and its density is 1.4 g/cm³, so that the rate of temperature rise on the surface of a coal particle is:

$$\frac{T_s}{t} = (200)(10^5)/[(1.4)(.5)]$$

$$= 3 \times 10^7 \text{°F/sec.}$$

where 1 watt = 1 Joule/sec.

Thus, the time needed to raise the temperature to 2200°C (4000°F) on the surface of an absorbing coal particle is

$$t = 4000/(3 \times 10^7) = 1.3 \times 10^{-4} \text{ sec.}$$

Case Study⁷

Hexachlorobenzene and sodium nitrite have been pyrolyzed in Thagard's bench-scale unit. The destruction and removal efficiency of both compounds have been greater than 99.99%. Hexachlorobenzene was used as a surrogate for PCB, because PCB requires special permits for testing.

Case to be Studied

Through a cooperative agreement, EPA and the State of California will support the Thagard Inc. to test their 3 inch diameter reactor in 1983. Compounds to be tested include:

General Class

Specific Compounds

- | | |
|-------------|--|
| A. Methane | a. Chloromethane, CH_3Cl
b. dichloromethane, CH_2Cl_2
c. trichloromethane (chloroform) CHCl_3
d. tetrachloromethane (carbon tetrachloride), CCl_4 |
| B. Ethylene | a. Vinyl chloride (monochloroethane), $\text{C}_2\text{H}_2\text{Cl}$ |
| C. Ethane | a. 1,2-dichloroethane, $\text{C}_2\text{H}_2\text{Cl}_2$
b. 1,1,1-trichloroethane (methyl chloroform), C_2HCl_3 |
| D. Benzene | a. Chlorobenzene, $\text{C}_6\text{H}_5\text{Cl}$
b. 1,2-dichlorobenzene, $\text{C}_6\text{H}_4\text{Cl}_2$
c. Hexachlorobenzene, C_6Cl_6 |

Technology Advantages

- The high operating temperature provides high radiant energy densities that should assure rupture of the chemical bonds, thus breaking the wastes into their simplest constituents, and eliminating the formation of intermediate products.
- The high temperature appears sufficient to destroy virtually any chemical bond and produce clean off-gases, thus avoiding the needs of off-gas clean-up systems.
- The solid residue is a glass-like particle that appears to be non-leachable. If this is indeed the case, the residue would not have to be disposed of in a secure chemical landfill.
- The configuration of the reactor and the nature of the process make scaling from pilot units a relatively simple procedure.
- The simplicity of design reduces capital outlay and maintenance costs.

Technology Disadvantages

- Solid wastes need to be ground to about 20 mesh size before processing.
- The reactor core can only accept solid materials. Therefore, if a waste is gaseous or liquid, it must be blended with non-hazardous solid materials to form a solid powder suitable for feeding.

4. Plasma Arc

Process Description

The plasma arc technology has been used in the United States space program. The evaluation of heat shields that protect space vehicles on re-entry required an intense heat source with plasma characteristics. The plasma was developed for that purpose. Initially, the plasma arcs destroyed themselves in a matter of minutes, although they were able to provide the plasma heating required for the space program. Subsequent developments have led to a plasma arc that does not consume its electrode, while producing a long plasma arc with excellent dimensional stability.

Plasmas have been referred to as the fourth state of matter since they do not always behave as a solid, liquid or gas. A plasma may be defined as a conductive gas flow consisting of charged and neutral particles, having an overall charge of approximately zero, and all exhibiting collective behavior.

The most common method of plasma generation is electrical discharge through a gas. Figure 6 shows a typical plasma reaction vessel schematic. A low pressure gas is used as a medium through which an electrical current is passed. The type of gas used is relatively unimportant in creating the discharge, but will ultimately affect the products formed. In passing through the gas, electrical energy is converted to thermal energy by the absorption of gas molecules, which are activated into ionized atomic states, losing electrons in the process. Arc temperatures up to 50,000°K may be achieved along the centerline recirculation vortex. Ultraviolet radiation is emitted when molecules or atoms relax from the highly activated states to lower energy levels.

The plasma, when applied to waste disposal, can best be understood by thinking of it as an energy conversion and energy transfer device. The electrical energy input is transformed into a plasma with a temperature equivalent of up to 50,000°K at the centerline of the reactor. As the activated components of the plasma decay, their energy is transferred to waste materials exposed to the plasma. The wastes are then atomized, ionized, pyrolyzed and finally destroyed as they interact with the decaying plasma species. The heart of this technology is that the atomization of wastes occurs virtually instantaneously and no large molecular intermediary compounds are produced during the kinetic recombination.

Case Study⁸

Laboratory-scale testing has shown that destruction efficiency of a few hundred gram liquid of polychlorinated biphenyl (PCB) when based on the amount of PCB recovered after testing, is better than 99.99% in all cases. No hexachlorobenzene nor PCB was found as a result of tests in which the product gas exit temperature was above 870°C at a residence time within the reactor of 1 second. A summary of some significant findings are quoted in Table 5.⁸ Destruction tests of larger quantities of PCB have not been conducted yet.

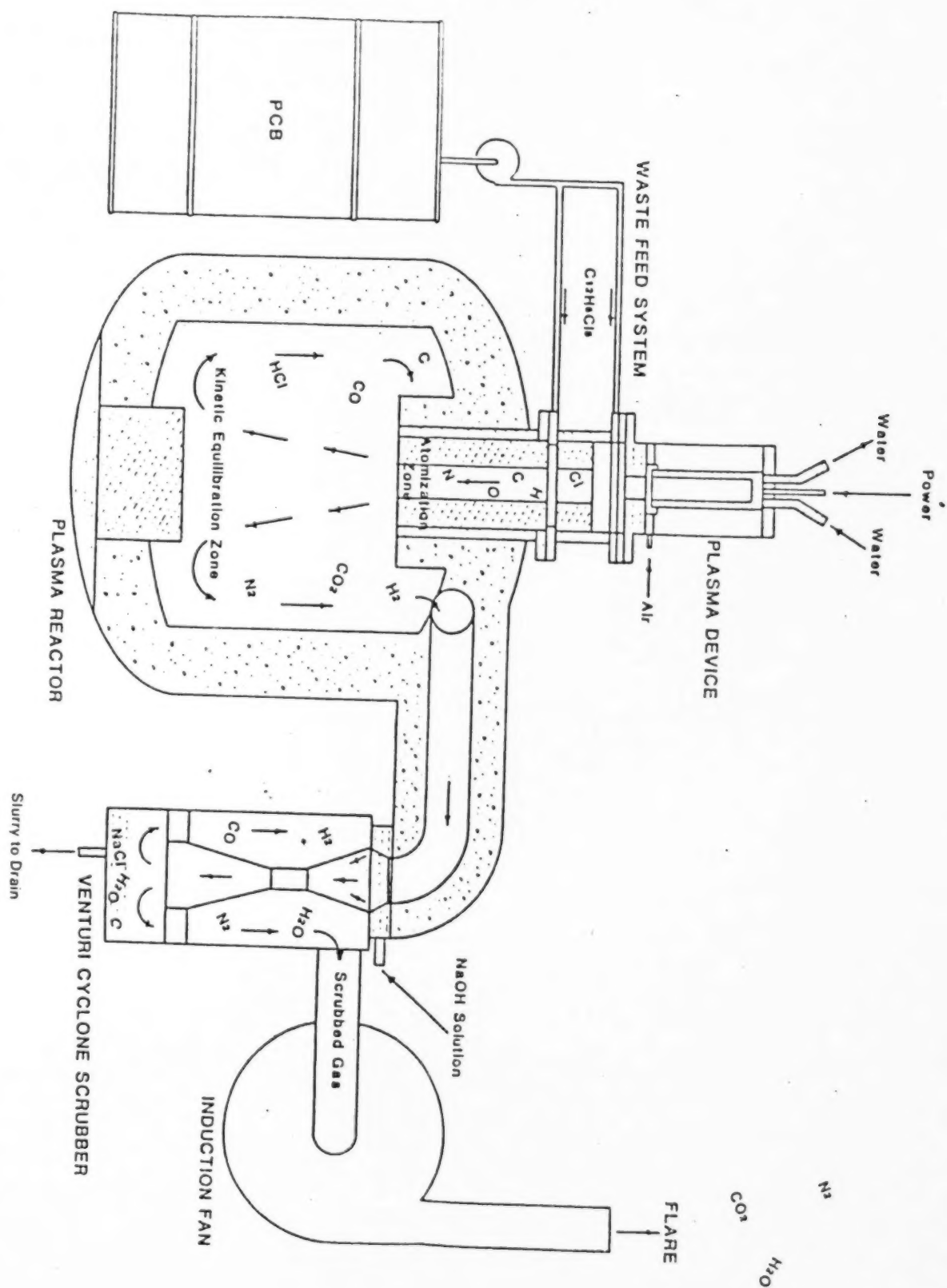


FIGURE 6. PLASMA REACTION VESSEL SCHEMATIC

TABLE 5. PLASMA TEST DATA

TEST 9 SEP 81

321.7 g TRICHLOROBENZENE (TCB) IN 3 L METHANOL WASTE	
TCB RESIDUE IN SCRUBBING RESERVOIR	- UNDETECTABLE
TCB MASS IN IMPINGERS	- 3.54 MG
CHLORINE RECOVERED	86%
DESTRUCTION EFFICIENCY	99.9989%

TEST 30 SEP 81

300.9 g TCB IN 3 L METHANOL WASTE	
TCB RESIDUE IN SCRUBBING RESERVOIR	- 0.48 MG
TCB MASS IN IMPINGERS	- 0.19 MG
CHLORINE RECOVERED	87%
DESTRUCTION EFFICIENCY	99.9998%

TEST 28 OCT 81

301.8 g TCB IN 3 L METHANOL WASTE	
TCB RESIDUE IN SCRUBBING RESERVOIR	- .28 MG
TCB RESIDUE IN IMPINGERS	- .21 MG
CHLORINE RECOVERED	79%
DESTRUCTION EFFICIENCY	99.9998%

Technology Advantages

- a. Since radiative heat transfer proceeds as a function of the fourth power of the temperature, a plasma system is capable of radiating energy much much faster than a conventional flame.
- b. Organic chlorides are known to dehalogenate when excited by ultraviolet radiation which is abundant from thermal plasmas.
- c. Using electricity as energy sources prevents emissions from burning auxiliary fuels. The vendor claims that 80% of input energy is transferred to the waste in the plasma reactor and 20% of heat lost to the surroundings.

Technology Disadvantages

Because temperature is so high (about 50,000°K at arc center line), the durability of the arc torch could be a potential problem.

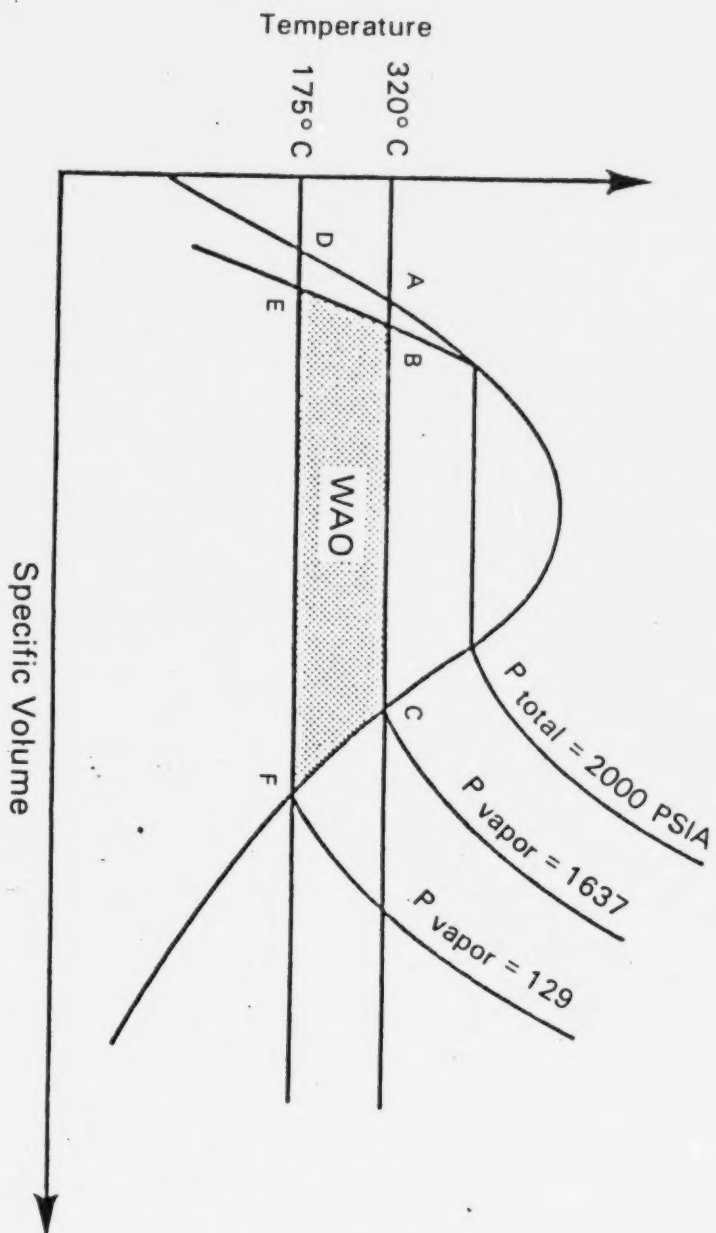
5. Wet Air Oxidation (WAO)

WAO has been used worldwide to treat both industrial municipal wastes for the last 30 to 40 years. Operating designs vary from low oxidations, for sludge conditioning, to high oxidations, for chemical and power recovery, and carbon regeneration. During recent years, bench-scale^{9,10} and pilot plant¹¹ testing has been performed by various companies to demonstrate the applicability of wet oxidation for the destruction of various hazardous organic wastes. Wet oxidation units currently detoxify specific waste streams at several generators.¹²

Wet air oxidation refers to the aqueous phase oxidation of dissolved or suspended organic substances at elevated temperatures and pressures. Water, which represents the aqueous phase, serves to catalyze the oxidation reactions so that they proceed at relatively low temperatures, (175°C to 345°C) and at the same time serves to moderate the oxidation rates removing excess heat by evaporation. Water also provides an excellent heat transfer medium which enables the wet air oxidation process to be thermally self-sustaining with relatively low organic feed concentration.

The oxygen required by the wet air oxidation reactions is provided by an oxygen-containing gas, usually air, bubbled through the liquid phase in a reactor used to contain the process; thus the commonly used term "wet air oxidation." The process pressure is maintained at a level high enough to prevent excessive evaporation of the liquid phase, generally between 200 and 3,000 psi.

A temperature-volume diagram, Figure 7, shows the operating zone of WAO. The water-waste mixture is maintained at the saturated zone within EBCF of Figure 7. For this particular case, total pressure is maintained at 2000 psi and temperature varies from 175°C to 350°C.



T = 320° C, P total = 2000 PSIA (P vapor = 1637, P air = 363)
 T = 175° C, P total = 2000 PSIA (P vapor = 129, P air = 1871)

FIGURE 7. WET AIR OXIDATION ZONE

Case Study¹²

In 1976, the EPA published a list of 65 compounds or classes of compounds having top priority for elimination from effluents. Based on chemical structure, Zimpro Inc. chose a variety of these compounds for study. Their results are shown on Tables 6 and 7.

The solutions resulting from the WAO of these compounds at 320°C and 2750C/1 hr were tested for toxicity using *Daphnia magna*. These results were compared with the toxicity of the starting compound. Toxicity reduction was quite good for all compounds studied. The data also indicates that compound destruction or toxicity reduction are nearly as good at 2750C as that obtained at 320°C.

These studies provided some empirical observations concerning a particular compound's susceptibility to conventional (with or without a copper catalyst) WAO based on its molecular structure.

- a. Aliphatic compounds, even with the multiple halogen atoms, can be destroyed within conventional WAO conditions. Formation of oxygenated compounds, such as low molecular weight alcohols, aldehydes, ketones and carboxylic acids result, but these are readily biotreatable.
- b. Aromatic hydrocarbons such as toluene, acenaphthene or pyrene are easily oxidized.
- c. Halogenated aromatic compounds can be oxidized provided there is at least one non-halogen functional group present on the ring, i.e., pentachlorophenol (-OH) or 2,4,6-trichloroaniline (-NH₂).
- d. Halogenated aromatic compounds such as 1,2-DCB or Aroclor 1254, a PCB, are resistant to conventional conditions, but can be oxidized in the presence of a copper catalyst.
- e. Halogenated condensed ring compounds, such as the pesticides aldrin, dieldrin or endrin, are expected to be resistant to conventional WAO but should be oxidizable in the presence of a copper catalyst.
- f. DDT, although destroyed, results in intractable oil formation on conventional WAO.
- g. Heterocyclic compounds containing O, N, or S atoms provide a point of attack for oxidation and are expected to be destroyed by WAO.

Case to be Studied

Casmalia Resource Management Inc. in California is in the process of installing a wet oxidation unit at the Casmalia industrial disposal site. The unit was manufactured by Zimpro Inc. and will be used to detoxify the wastes selected from classified groups of organic wastes from treater's

TABLE 6.
WET AIR OXIDATION
(ONE HOUR OXIDATION)

COMPOUND	STARTING CONC.	% STARTING MATERIAL DESTROYED		
		3200C	2750C	2750C/Cu**
ACENAPHTHENE	7.0 g/L	99.96%	99.99%	
ACROLEIN	8.41g/L	> 99.96%*	> 99.05%*	
ACRYLONITRILE	8.06g/L	99.91%	99.00%	99.50%
2-CHLOROPHENOL	12.41g/L	99.86%	94.96%	99.88%
2,4-DIMETHYLPHENOL	8.22g/L	99.99%	99.99%	
2,4-DINITROTOLUENE	10.0 g/L	99.88%	99.74%	
1,2-DIPHENYLHYDRAZINE	5.0 g/L	99.98%	99.88%	
4-NITROPHENOL	10.0 g/L	99.96%	99.60%	99.97%
PENTACHLOROPHENOL	5.0 g/L	99.88%	81.96%	97.30%
PHENOL	10.0 g/L	99.97%	99.77%	99.93%

*THE CONCENTRATION REMAINING WAS LESS THAN THE DETECTION LIMIT OF 3 MG/L.

**Cu IS USED AS THE CATALYST.

TABLE 7.
WET AIR OXIDATION
(ONE HOUR WITH/WITHOUT CATALYST)

COMPOUND	TEMP.	CATALYST	% DESTROYED
SODIUM CYANIDE (NaCN)	275°C	0	99.96
POTASSIUM THIOCYANATE (KSCN)	275°C	0	99.98
FORMIC ACID (CO ₂ H ₂)	275°C	0	99.3
N-NITROSODIMETHYLAMINE (C ₂ H ₆ N ₂ O)	275°C	0	99.56
	275°C	+	99.38
TOLUENE (C ₇ H ₆)	275°C	0	99.73
	275°C	+	99.96
PYRENE (C ₁₆ H ₁₀)	275°C	0	99.995
	275°C	+	99.997
MALATHION (C ₁₀ H ₁₉ O ₆ PS ₂)	200°C	0	99.87
	250°C	0	99.85
	300°C	0	99.97
1,2-DICHLOROETHANE (C ₂ H ₄ Cl ₂)	275°C	0	99.8
	275°C	+	99.9
CHLOROFORM (CHCl ₃)	275°C	0	99.92
	275°C	+	99.94
CARBON TETRACHLORIDE (CCl ₄)	275°C	0	99.99
	275°C	+	99.99

facilities. These classified groups will be cyanide wastes, phenolic wastes, sulfide wastes, non-halogenated pesticides, solvent still bottoms, and general wastewaters. In addition, through the cooperative agreement, EPA and the State of California will support Zimpro Inc. to test the following compounds on the unit.

<u>General Class</u>	<u>Specific Compounds</u>
A. Methane	a. Chloroform b. Carbon tetrachloride c. Methylene chloride
B. Ethylene	a. Vinyl chloride
C. Ethane	a. Dichloroethane b. 1,1,1-trichloroethane
D. Aromatics	a. Benzene b. Toluene c. Xylene
E. Others	a. Organic and inorganic cyanides b. Organic and inorganic sulfur compounds c. Phenols d. Pesticides (non-halogenated aromatics)

Oxidation results will then be collected such that predictions might be made for all the compounds in a particular group.

The waste to be tested will be selected from those collected by the commercial treater or those supplied by the Environmental Protection Agency or its supervising contractor. A preliminary autoclave wet oxidation test will be run where necessary to insure compatibility and treatability with the existing unit. It is expected that a continuous test of a minimum of eight hours will be run for each waste. The unit will operate at 10 gpm with a waste having a COD of up to 46 grams/liter. Waste with higher concentrations will be run at lesser flow rates. The unit will be operated at its designed operating temperature of 300°C unless there is good cause to believe that the waste would/could be processed at a lower condition. Samples of feed and effluent will be analyzed to determine effectiveness of treatment.

Technology Advantages

- Since oxidation takes place in the liquid state, it is not necessary to evaporate water content of the waste. The process therefore is most useful for wastes which are too dilute to incinerate economically yet too toxic to treat biologically.
- Because wet oxidation reactions take place in the liquid phase, the process can operate without consumption of heat for vaporizing water and organics. The sensible heat required to heat the waste to reaction temperature is recovered from the effluent by heat exchangers.

Technology Disadvantages

At elevated temperatures and pressures, WAO may require the use of high alloy materials such as titanium to prevent corrosion. This use of high alloys increase capital costs.

6. Supercritical Fluid (SCF)

SCF is characterized as a form of matter in which the liquid and gaseous states are indistinguishable from one another. It is formed when both temperatures and pressures to which the fluid is subjected exceed the critical point (T_c and P_c) as shown in Figure 8. Under these supercritical states, the character of the fluid becomes very unusual compared to that under ambient conditions. For example¹³, if water is under the supercritical conditions, the density, dielectric constant, hydrogen bonding, and certain other physical properties are so altered that water behaves much as a moderately polar organic liquid. Thus, n-heptane or benzene, could become miscible in all proportions with SCW (supercritical water) which cannot happen with water under sub-critical conditions. Even some types of wood fully dissolve in SCW. On the other hand, the solubility of sodium chloride (NaCl) could be as low as 100 ppm, and that of calcium chloride can be less than 10 ppm. This is the reverse of the solubilities in water that are encountered under sub-critical conditions - under which the two salts' solubilities are about 37 wt % and up to 70 wt %, respectively. These phenomena are shown in Figure 9¹³. Table 8 shows critical conditions/ common fluids.

The SCF region can best be visualized with the aid of a reduced pressure and volume diagram. The reduced pressure, temperature and volume are defined as:

$$P_r = \frac{P}{P_c}, T_r = \frac{T}{T_c}, V_r = \frac{V}{V_c}$$

where, the subscript r and c denotes a reduced property and the property at the critical point respectively. Table 8 shows critical conditions of common fluids.

In the study of using supercritical CO₂ for the regeneration of activated carbon, Arthur D. Little, Inc.¹⁵ is suggesting that the SCF region be in the range of 1 to 1.4 of reduced temperatures and 1 to 6 of reduced pressures as shown in Figure 8.

Case study

Modar Inc.¹⁴ has conducted an extensive series of bench-scale tests to establish the technical feasibility of SCW oxidation. A summary of the test results is given in Tables 9 and 10.

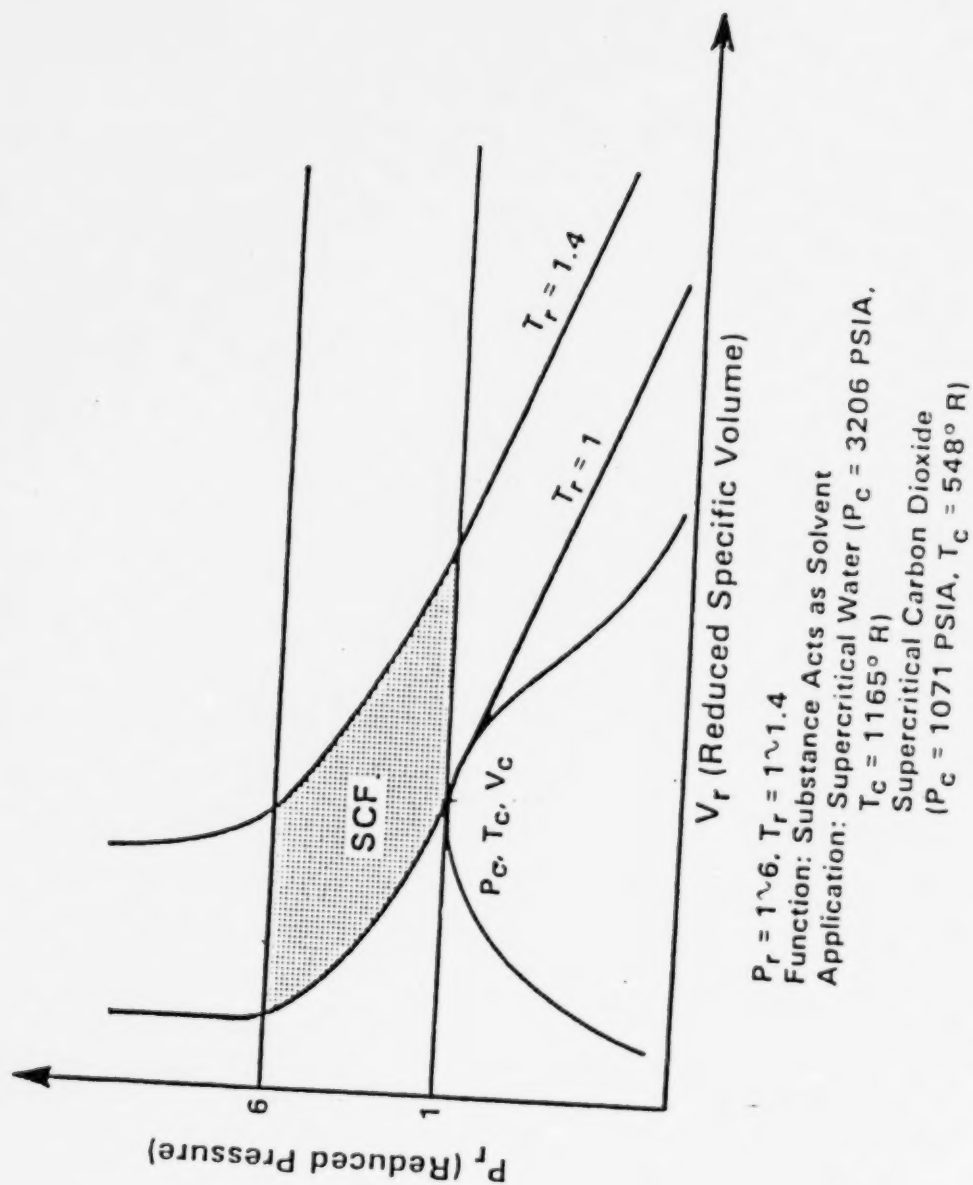


FIGURE 8. SUPERCRITICAL FLUID (SCF) OPERATION ZONE

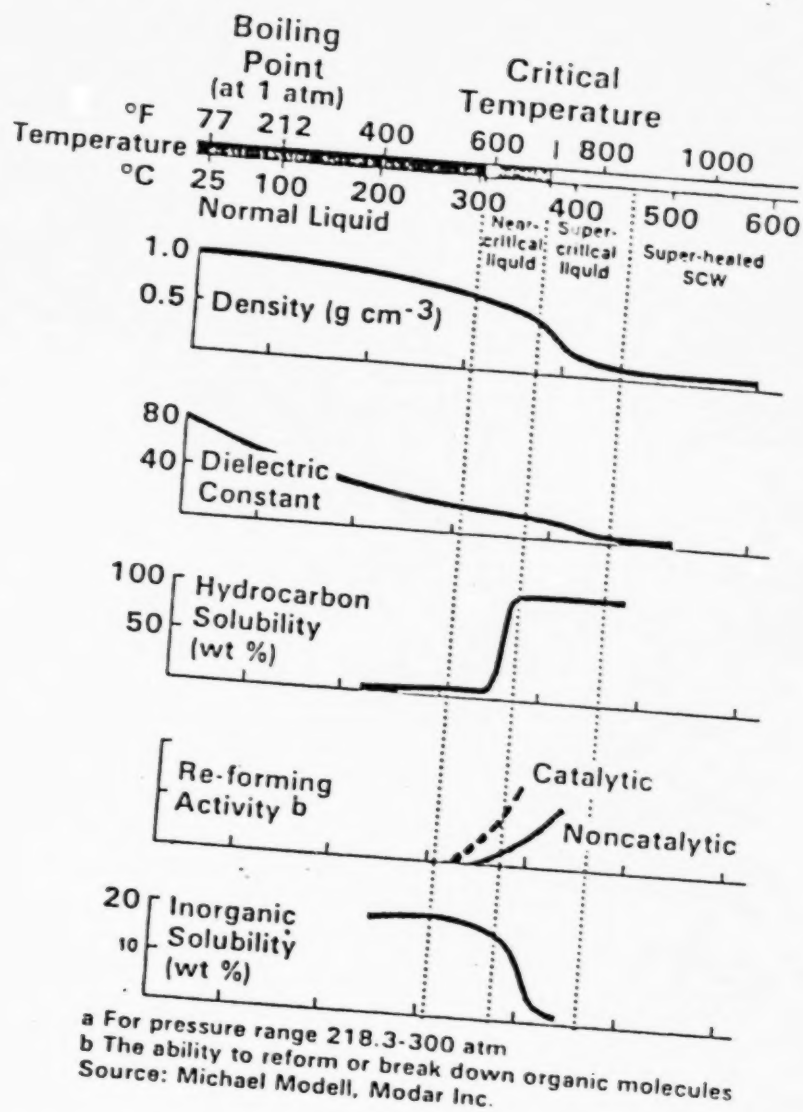


FIGURE 9. PROPERTY OF WATER AT SUPERCRITICAL CONDITIONS

TABLE 8.
CRITICAL CONDITIONS OF COMMON FLUIDS

	$T_c (^{\circ}\text{C})$	$P_c (\text{ATM})$	$P_c (\text{G/CM}^3)$
ETHYLENE	9.9	50.5	0.23
CARBON DIOXIDE	31.0	72.9	0.47
ETHANE	32.2	48.2	0.20
METHYL FLUORIDE	44.6	58.0	0.31
SULFUR HEXAFLUORIDE	45.6	37.1	0.75
PROPYLENE	91.9	45.4	0.23
PROPANE	96.7	42.0	0.22
CARBON DISULFIDE	104.8	65.	0.45
AMMONIA	132.3	111.3	0.24
N-BUTANE	152.0	37.5	0.23
SULFUR DIOXIDE	157.5	77.7	0.53
NITROGEN DIOXIDE	157.8	100.	0.56
N-PENTANE	196.6	33.3	0.23
N-HEXANE	234.2	29.6	0.23
ACETONE	235.9	47.	0.28
METHANOL	240.3	78.9	0.27
ETHANOL	243.4	63.0	0.28
CHLOROFORM	263.4	54.	0.50
N-HEPTANE	267.0	27.0	0.24
BENZENE	288.9	48.3	0.30
WATER	374.	218.	0.32

TABLE 9. COMPOSITION OF FEED MIXTURES FOR RUNS 11 - 15

Run 11 DDT		wt %	wt % Cl
MEK	C ₁₄ H ₉ Cl ₅	4.32	2.133
	C ₄ H ₈ O	95.68 100.0	- 2.133
Run 12 1,1,1-trichloroethane	C ₂ H ₃ Cl ₃	1.01	0.806
1,2-ethylene dichloride	C ₂ H ₂ Cl ₂	1.01	0.739
1,1,2,2-tetrachloroethylene	C ₂ Cl ₄	1.01	0.866
o-chlorotoluene	C ₇ H ₇ Cl	1.01	0.282
1,2,4-trichlorobenzene	C ₆ H ₃ Cl ₃	1.01	0.591
biphenyl	C ₁₂ H ₁₀	1.01	-
o-xylene	C ₈ H ₁₀	5.44	-
MEK	C ₄ H ₈ O	88.48 100.0	- 3.284
Run 13 hexachlorocyclohexane	C ₆ H ₆ Cl ₆	0.69	0.497
DDT	C ₁₄ H ₉ Cl ₅	1.00	0.493
4,4'-dichlorobiphenyl	C ₁₄ H ₈ Cl ₂	1.57	0.495
Hexachlorocyclopentadiene	C ₅ Cl ₆	0.65	0.505
MEK	C ₄ H ₈ O	96.09 100.0	- 1.99
Run 14 PCB 1242	C ₁₂ H _x Cl ₄₋₆	0.34	0.14
PCB 1254	C ₁₂ H _x Cl ₅₋₈	2.41	1.30
transformer oil	C ₁₀ -C ₁₄	29.26	-
MEK	C ₄ H ₈ O	67.99 100.0	- 1.44
Run 15 4,4'-dichlorobiphenyl	C ₁₂ H ₈ Cl	3.02	.96
MEK	C ₄ H ₈ O	96.98 100.0	- 0.96

TABLE 10. SUMMARY OF RESULTS: OXIDATION OF ORGANIC CHLORIDES

<u>Run No.</u>	11	12	13	14	15
<u>Residence Time (min)</u>	1.1	1.1	1.1	1.1	1.3
<u>Carbon Analysis</u>					
Organic Carbon In (ppm)	26,700.	25,700.	24,500.	38,500.	33,400.
Organic Carbon Out (ppm)	2.0	1.0	6.4	3.5	9.4
Destruction Efficiency (%)	99.993	99.996	99.975	99.991	99.97
Combustion Efficiency (%)	100.	100.	100.	100.	100.
<u>Gas Composition</u>					
O ₂	25.58	32.84	37.10	10.55	19.00
CO ₂	59.02	51.03	46.86	70.89	70.20
CH ₄	-	-	-	-	-
H ₂	-	-	-	-	-
CO	-	-	-	-	-
<u>Chloride Analysis</u>					
Organic Chloride In (ppm)	876.	1266.	748.	775.	481.
Organic Chloride Out (ppm)	.023	.037	<.028	.032	.036
Organic Chloride Conversion (%)	99.997	99.997	99.996	99.996	99.993

Technology Advantages and Disadvantages

In general, SCF has the same technology advantages and disadvantages as stated in WAO. However, there are two basic differences:

1. WAO requires longer residence times of 20 minutes to 1 hour, compared to SCW which requires residence times of generally less than 1 minute, thus reducing the volume of the oxidizer.
2. The SCF vessel requires much higher temperature and pressure to maintain the mixture at the supercritical conditions.

COMPOUND SELECTION

In 1980, EPA published a comprehensive list of hazardous wastes¹⁶. The list contains 16 classes of waste from nonspecific sources (F001-F016), 69 classes of waste from specific sources (K001-K069), 122 acute wastes (P001-P122) and 239 toxic wastes (V001-V239) from discarded commercial products, off-specification species, containers, and spill residues. Details of the list are provided in the Attachment.

Practically speaking, it is impossible to test every compound in an incinerator to obtain its destruction and removal efficiency (DRE). In 1981, EPA selected eleven representative compounds (Table 11) for various studies. They were selected based on the following criteria:

1. Frequency of appearance in hazardous waste categories.
2. Quantity of generation estimated.
3. Compounds already tested by other EPA studies.
4. Groups of chemical structure.
5. Compound structure..

The major advantage of testing these representative compounds on different technologies is that comparable data can be obtained to establish the DRE matrix among different technologies under different operating conditions. Establishing the comparable data can be beneficial to both vendors and potential users, because one can easily compare a technology against the others. Therefore, it is recommended that those who are involved in hazardous waste testing use these representative compounds to test the technologies to be evaluated. The vendors of high temperature fluid wall and wet air oxidation have agreed with this testing recommendation and will test these compounds in their respective technologies.

TABLE 11.
REPRESENTATIVE COMPOUNDS

CHEMICAL STRUCTURE		FORM
I	METHANE-BASED GROUP	
	1. METHYLENE CHLORIDE, CH_2Cl_2	LIQUID
	2. CHLOROFORM, CHCl_3	LIQUID
	3. CARBON TETRACHLORIDE, CCl_4	LIQUID
II	ETHENE-BASED GROUP	
	4. VINYL CHLORIDE (VCM), $\text{C}_2\text{H}_2\text{Cl}$	GAS
III	ETHANE-BASED GROUP	
	5. 1,2 DICHLOROETHANE, $\text{C}_2\text{H}_4\text{Cl}_2$	LIQUID
	6. 1,1,1 TRICHLOROETHANE, $\text{C}_2\text{H}_3\text{Cl}_3$	LIQUID
IV	AROMATIC-BASED GROUP	
	7. BENZENE, C_6H_6	LIQUID
	8. CHLOROBENZENE, $\text{C}_6\text{H}_5\text{Cl}$	LIQUID
	9. 1,2 DICHLOROBENZENE, $\text{C}_6\text{H}_4\text{Cl}_2$	LIQUID
	10. HEXACHLOROBENZENE, C_6Cl_6	SOLID
V	OTHERS	
	11. ACRYLONITRILE, $\text{C}_3\text{H}_3\text{N}$	LIQUID

COMPARISON OF SIX SELECTED TECHNOLOGIES

Based on the above representative 11 compounds, and data available from vendors of the six-selected technologies, Table 12 has been constructed to compare their relative DRE, residence time and temperature. Although PCB was not selected as a representative compound, it was included in Table 12, because PCB has been tested by many technologies. The reason PCB was not selected as the representative compound is because PCB is regulated by a different Act, i.e., the Toxic Substance Control Act (TSCA).

A review of Table 12 shows that:

1. Tests of a few technologies have shown that the selected waste can be destroyed to meet the 99.99% DRE requirement.
2. Wet air oxidation apparently has the lowest temperature and the longest residence time requirement.
3. Plasma has the highest temperature characteristic.
4. Supercritical water has the highest pressure requirement (however, this is not shown in Table 12).

Unfortunately, due to lack of consistent information, Table 12 can only provide a limited comparison. For example, there is no data from fluidized bed combustion in their testing category. It is believed, however, that as time goes on, more data, especially cost data, will be available for comparison, thus comparison will be more meaningful to assist industry in selecting technology for application.

TABLE 12.
DRE COMPARISON OF SIX SELECTED TECHNOLOGIES

Compound*	CHARACTERISTICS			PROCESS	MANUFACTURER
	DRE	T(°C)	T(sec.)		
CHLOROFORM	>99.99	818	0.5	MOLTEN SALT	ROCKWELL
CHLOROFORM	99.94	275	3600.0	WAO	ZIMPRO
CARBON TETRACHLORIDE	99.99	275	3600.0	WAO	ZIMPRO
1,2 DICHLOROETHANE	99.9	275	3600.0	WAO	ZIMPRO
1,1,1 TRICHLOROETHANE	>99.99	400	66.0	SCF	MODAR INC.
HEXACHLOROBENZENE	>99.99	1000	3.0	MOLTEN SALT	ROCKWELL
HEXACHLOROBENZENE	ND	4000	1.0	HTFW	THAGARD
ACRYLONITRILE	99.91	320	3600.0	WAO	ZIMPRO
POLYCHLORINATED BIPHENYLS (PCB)	>99.99	750- 900	0.5	MOLTEN SALT	ROCKWELL
PCB	ND	50,000	1.0	PLASMA ARC	PLASMA RESEARCH

*NO INFORMATION FOR THE FOLLOWING COMPOUNDS: METHYLENE CHLORIDE, VINYL CHLORIDE, BENZENE, CHLOROBENZENE, 1,2 DICHLOROBENZENE.

REFERENCES

1. U.S. Environmental Protection Agency, "Engineering Handbook for Hazardous Waste Incineration," Publication No. SW-889, September 1981.
2. "Hazardous Waste Incineration: Current/Future Profile," C.C. Lee, E. Keitz and G.A. Vogel. 3rd National Conference and Exhibition on Management of Uncontrolled Hazardous Waste Sites, Washington D.C., November 29 December 1, 1982.
3. "Destroying Chemical Wastes in Commercial Scale Incinerators Facility Report No. 3 - System Technology," NTIS, PB-265-540, 1977.
4. "Method of Catalytically Inducing Oxidation of Carbonaceous Materials by the Use of Molten Salts," J. Greenberg, United States Patent 3, 647, 358, assigned to Anti-Pollution Systems, Inc., Pleasantville, New Jersey, 1972, 16 pp.
5. "Treatment of Sewage and Other Contaminated Liquids with recovery of Water by Distillation and Oxidation," J. Greenberg and D.C. Whitaker. United States Patent 3, 642, 583, assigned to Anti-Pollution Systems, Inc., Pleasantville, New Jersey, 1972, 10 pp.
6. "Disposal of hazardous wastes by molten salt combustion," S.J. Yosium, et. al. Paper presented at the American Chemical Society Meeting, Hawaii, 1979.
7. "Management of Toxic Wastes with the Thagard High Temperature Fluid Wall Reactor," E. Matovich. Presented at the AIChE Southern California Section, April 21, 1981.
8. "Plasma Destruction of Polychlorinated Biphenyls," T.G. Barton. Prepared for the Ministry of Environment, Province of Ontario, Canada, March 1982.
9. "Detoxification of Specific Organic Substances by Wet Oxidation," T.L. Randall, P.V. Knopp. 51st Annual Conference; WPCF. Anaheim, October 1978.
10. "Wet Oxidation of Toxic and Hazardous Compounds," T.L. Randall. Mid-Atlantic Industrial Waste Disposal Conference, University of Delaware, 1981.
11. "Treatment of Spent Caustic Liquors by Wet Oxidation," A.K. Chowdhury, A.R. Wilhelmi. 8th Annual Industrial Pollution Conference, June 1980, Houston.
12. "Wet Air Oxidation of Northern Petrochemical Company Spent Caustic Liquors," D.J. DeAngelo, A.R. Wilhelmi. 1982 Spring National AIChE Meeting, Anaheim, California, 1982.
13. "Supercritical Fluids," Environmental Science Technology, Vol. 16 No. 10, 1982.

14. "Destruction of Hazardous Waste Using Supercritical Water," M. Modell, et. al.
15. "Supercritical Fluid Regeneration of Activated Carbon for Adsorption of Pesticides," EPA 600/2-80-054, March 1980.
16. "Hazardous Waste Management System," Federal Register, Vol. 45, No. 98, May 19, 1980.

Hazardous waste from nonspecific sources.

Industry and EPA hazardous waste No.	Hazardous waste	Hazard code
Generic:		
F001	The spent halogenated solvents used in degreasing, tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and the chlorinated fluorocarbons, and sludges from the recovery of these solvents in degreasing operations	(M)
F002	The spent halogenated solvents, tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-dichloro-1,2,2-trifluoroethane, o-dichlorobenzene, trichlorofluoromethane and the still bottoms from the recovery of these solvents	(M)
F003	The spent non-halogenated solvents, xylene, acetone, ethyl acetate, ethyl benzene, ethyl ether, n-butyl alcohol, cyclohexanone, and the still bottoms from the recovery of these solvents	(M)
F004	The spent non-halogenated solvents, cresols and cresylic acid, nitrobenzene, and the still bottoms from the recovery of these solvents	(M)
F005	The spent non-halogenated solvents, methanol, toluene, methyl ethyl ketone, methyl isobutyl ketone, carbon disulfide, isobutanol, pyridine, and the still bottoms from the recovery of these solvents	(M)
F006	Wastewater treatment sludges from electroplating operations	(M, T)
F007	Spent plating bath solutions from electroplating operations	(M, T)
F008	Plating bath sludges from the bottom of plating operations	(M, T)
F009	Spent stripping and cleaning bath solutions from electroplating operations	(M, T)
F010	Quenching bath sludge from oil baths from metal heat treating operations	(M, T)
F011	Spent solutions from salt bath pot cleaning from metal heat treating operations	(M, T)
F012	Quenching wastewater treatment sludges from metal heat treating operations	(M, T)
F013	Filtration sludges from selective filtration from metal heat treating operations	(M, T)
F014	Cyanidation wastewater treatment sludge pond sediment from mineral metals recovery operations	(M, T)
F015	Spent cyanide bath solutions from mineral metals recovery operations	(M, T)
F016	Deaerated air pollution control scrubber sludges from coke ovens and blast furnaces	(M, T)

Hazardous waste from specific sources.

Industry and EPA hazardous waste No.	Hazardous waste	Hazard code
Wood Preservation: K001	Bottom sediment sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or pentachlorophenol	(M)
Inorganic Pigments		
K002	Wastewater treatment sludge from the production of chrome yellow and orange pigments	(M)
K003	Wastewater treatment sludge from the production of molybdate orange pigments	(M)
K004	Wastewater treatment sludge from the production of zinc yellow pigments	(M)
K005	Wastewater treatment sludge from the production of chrome green pigments	(M)
K006	Wastewater treatment sludge from the production of chrome oxide green pigments (anhydrous and hydrated)	(M)
K007	Wastewater treatment sludge from the production of iron blue pigments	(M)
K008	Oven residue from the production of chrome oxide green pigments	(M)
Organic Chemicals		
K009	Distillation bottoms from the production of acetaldehyde from ethylene	(M)
K010	Distillation side cuts from the production of acetaldehyde from ethylene	(M)
K011	Bottom stream from the wastewater stripper in the production of acrylonitrile	(M)
K012	Still bottoms from the final purification column in the production of acrylonitrile	(M)
K013	Bottom stream from the acrylonitrile column in the production of acrylonitrile	(M, T)
K014	Bottoms from the acrylonitrile purification column in the production of acrylonitrile	(M, T)
K015	Still bottoms from the distillation of benzyl chloride	(M, T)
K016	Heavy ends or distillation residues from the production of carbon tetrachloride	(M, T)
K017	Heavy ends (still bottoms) from the purification column in the production of spichlorhydrin	(M, T)
K018	Heavy ends from fractionation in ethyl chloride production	(M, T)
K019	Heavy ends from the distillation of ethylene dichloride in ethylene dichloride production	(M, T)
K020	Aqueous spent antimony catalyst waste from fluoromethanes production	(M, T)
K021	Distillation bottom tars from the production of phenol/acetone from cumene	(M, T)
K022	Distillation light ends from the production of phthalic anhydride from naphthalene	(M, T)
K023	Distillation bottoms from the production of phthalic anhydride from naphthalene	(M, T)
K024	Distillation bottoms from the production of nitrobenzene by the nitration of benzene	(M, T)
K025	Stripping still tails from the production of methyl ethyl pyridines	(M, T)
K026	Centrifuge residue from toluene dicyclopentadiene production	(M, T)
K027	Spent catalyst from the hydrochlorinator reactor in the production of 1,1,1-trichloroethane	(M, T)
K028	Waste from the product stream stripper in the production of 1,1,1-trichloroethane	(M, T)
K029	Column bottoms or heavy ends from the combined production of trichloroethylene and perchloroethylene	(M, T)
Pesticides		
K030	By-products salts generated in the production of MSMA and cacodylic acid	(M)
K031	Wastewater treatment sludge from the production of chlordane	(M)
K032	Wastewater and scrub water from the chlorination of cyclopentadiene in the production of chlordane	(M)
K033	Filter solids from the filtration of hexachlorocyclopentadiene in the production of chlordane	(M)
K034	Wastewater treatment sludges generated in the production of creosote	(M)
K035	Still bottoms from toluene reclamation distillation in the production of disulfoton	(M)
K036	Wastewater treatment sludges from the production of disulfoton	(M)
K037	Wastewater from the washing and stripping of phorate production	(M)
K038	Filter cake from the filtration of dimethylphosphorodithioic acid in the production of phorate	(M)
K039	Wastewater treatment sludge from the production of phorate	(M)
K040	Wastewater treatment sludge from the production of toxaphene	(M)
K041	Heavy ends or distillation residues from the distillation of tetrachlorobenzene in the production of 2,4,5-T	(M)
K042	2,6-Dichlorophenol waste from the production of 2,4,5-T	(M)
Explosives		
K043	Wastewater treatment sludges from the manufacturing and processing of explosives	(M)
K044	Spent carbon from the treatment of wastewater containing explosives	(M)
K045	Wastewater treatment sludges from the manufacturing, formulation and loading of lead-based initiating compounds	(M)
K046	Pink/red water from TNT operations	(M)
Petroleum Refining		
K047	Dewatered air flotation (DAF) float from the petroleum refining industry	(M)
K048	Sink oil emulsion solids from the petroleum refining industry	(M)
K049	Heat exchanger bundle cleaning sludge from the petroleum refining industry	(M)
K050	API separator sludge from the petroleum refining industry	(M)
K051	Tank bottoms (residue) from the petroleum refining industry	(M)
Leather Tanning/Finishing		
K052	Chrome (blue) trimmings generated by the following subcategories of the leather tanning and finishing industry: raw pulp/chrome tan/retan/wet finish, hair save/chrome tan/retan/wet finish, no beamhouse, through the blue, and shearing	(M)

Hazardous waste from specific sources. —Continued

Industry and EPA hazardous waste No.	Hazardous waste	Hazard code
K054	Chrome (blue) shavings generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; no beamhouse, through the-blue and shearing.	(T)
K055	Buffing dust generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; no beamhouse, and through the-blue.	(T)
K056	Sewer screenings generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; no beamhouse, through the-blue and shearing.	(T)
K057	Wastewater treatment sludges generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; no beamhouse, through the-blue and shearing.	(T)
K058	Wastewater treatment sludges generated by the following subcategories of the leather tanning and finishing industry: hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish, and through the-blue.	(R, T)
K059	Wastewater treatment sludges generated by the following subcategory of the leather tanning and finishing industry: hair save/non-chrome tan/retan/wet finish.	(R)
Iron and Steel		
K060	Ammonia still line sludge from coking operations.	(T)
K061	Emission control dust/sludge from the electric furnace production of steel.	(T)
K062	Spent pickle liquor from steel finishing operations.	(C, T)
K063	Sludge from lime treatment of spent pickle liquor from steel finishing operations.	(T)
Primary Copper: K064	Acid plant blowdown slurry/sludge resulting from the thickening of blowdown slurry from primary copper production.	(T)
Primary Lead: K065	Surface impoundment solids contained in and dredged from surface impoundments at primary lead smelting facilities.	(T)
Primary Zinc:		
K066	Sludge from treatment of process wastewater and/or acid plant blowdown from primary zinc production.	(T)
K067	Electrolytic anode slimes/sludges from primary zinc production.	(T)
K068	Cadmium plant leach residue (iron oxide) from primary zinc production.	(T)
Secondary Lead: K069	Emission control dust/sludge from secondary lead smelting.	(T)

C = Corrosive waste

E = Toxic waste

H = Acute hazardous waste

I = Ignitable waste

R = Reactive waste

T = Toxic waste

Acute Hazardous Waste

Hazardous waste No.	Substance
	1080 see P058
	1081 see P057
	(Acetylphenyl)mercury see P092
	Acetone cyanohydrin see P068
P001	3-(alpha-Acetoxybenzyl)-4-hydroxycoumarin and salts
P002	1-Acetyl-2-thiourea
P003	Acropen
	Agaric see P007
	Agrosan GN 5 see P092
	Aldicarb see P068
	Aldrin see P048
P004	Aldrin
	Alginic acid see P092
P005	Allyl alcohol
P006	Aluminum phosphide (P)
	ALVIT see P037
	Ammonothylene see P054
P007	5-(Ammonomethyl)-3-oxazolid
P008	4-Aminopyridine
	Ammonium metavanadate see P118
P009	Ammonium persulfate (P)
	ANTIMUCIN WDR see P092
	ANTURAT see P073
	AQUATHOL see P068
	ARETTT see P020
P010	Arsenic acid
P011	Arsenic pentoxide
P012	Arsenic trioxide
	Atrombin see P001
	AVITROL see P008
	Azodene see P054
	AZOFOS see P081
	Azophos see P081
P013	BANTU see P072
	Barium cyanide
	BASENITE see P020
	BCME see P018
P014	Benzeneethiol
	Benzocoumarin see P050
P015	Beryllium dust
P016	Bis(chloromethyl) ether
P017	BLADAN M see P071
P018	Bromocoumarin
P019	Brucine
	2-Butanone peroxide
	BUFEN see P092
P020	Butachene see P020
P021	2-sec-Butyl-4,6-dinitrophenol
	Calcium cyanide
P022	CALDON see P020
	Carbon disulfide
	CERESAN see P092
	CERESAN UNIVERSAL see P092
	CHEMOX GENERAL see P020
	CHEMOX P.E. see P020
	CHEM-TOL see P090
P023	Chloroacetaldehyde
P024	p-Chloroaniline
P025	1-(p-Chlorobenzoyl)-5-methoxy-2-methylindole-3-acetic acid
P026	1-(p-Chlorophenyl)thiourea
P027	3-Chloropropionitrile
P028	alpha-Chlorotoluene
P029	Copper cyanide
	CRETOX see P108
	Coumadin see P001
	Coumatan see P001
P030	Cyanides
P031	Cyanogen
P032	Cyanogen bromide
P033	Cyanogen chloride
	Cyclodan see P050
P034	2-Cyclohexyl-4,6-dinitrophenol
	D-CON see P001
	DETHACOR see P001
	DETHNEL see P001
	DFF see P043
P035	2,4-Dichlorophenoxyacetic acid (2,4-D)
P036	Dichlorophenylsine
P037	Dicyanogen see P031
	Deklin
P038	DELDREX see P037
	Demylarsine
P039	0,0-Diethyl S-(2-ethylthio)ethylphosphorothioic acid

Hazardous waste No.	Substance
P040	0,0-Diethyl-O-(2-pyrazinyl)phosphorothioate
P041	0,0-Diethyl phosphoric acid, O-p-nitrophenyl ester
P042	3,4-Dihydroxy-alpha-(methylamino)-methyl benzyl alcohol
P043	Di-n-propylfluorophosphate
	DIMETATE see P044
	1,4,5,8-Dimethanonaphthalene, 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-endo-endo see P060
P044	Dimethoate
P045	3,3-Dimethyl-1-(methylthio)-2-butanone-O-[(methylamino)carbonyl] oxime
P046	alpha,alpha-Dimethylphenethylamine
	Dinitrocyclohexylphenol see P034
P047	4,6-Dinitro-o-cresol and salts
P048	2,4-Dinitrophenol
	DINOSEB see P020
	DINOSEBE see P020
	Disulfoton see P039
P049	2,4-Dinitrophenol
	DNBP see P020
	DOLCO MOUSE CEREAL see P108
	DOW GENERAL see P020
	DOW GENERAL WEED KILLER see P020
	DOW SELECTIVE WEED KILLER see P020
	DOWICIDE G see P090
	DYANACIDE see P092
	EASTERN STATES DUOXIDE see P001
	ELGETOL see P020
P050	Endosulfan
P051	Endrin
	Ephedrine see P042
P052	Ethylcyanide
P053	Ethylmethamine
P054	Ethylamine
	FASCO FASCIAT POWDER see P001
	FEMMA see P091
P055	Femic cyanide
P056	Fluorene
P057	2-Fluorobenzamide
P058	Fluoracetic acid, sodium salt
	FOLODOL 80 see P071
	FOLODOL M see P071
	FOSFERNO M 50 see P071
	FRATOL see P058
	Fuminate of mercury see P065
	FUNGITOX OR see P092
	FUSSOK see P057
	GALLOTOX see P092
	GEARPHOS see P071
	GERUTOX see P020
P059	Heptachlor
P060	1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-1,4,5,8-endo-endo-dimethanonaphthalene
	1,4,5,8,7,7-Hexachloro-cyclo-5-norbornene-2,3-dimethanol sulfite see P050
P061	Hexachloropropene
P062	Hexaethyl tetraphosphate
	HOSTAQUICK see P092
	HOSTAQUICK see P092
	Hydrazomethane see P068
P063	Hydrocyanic acid
	ILLOXOL see P037
	INDOCI see P025
	Indomethacin see P025
	INSECTOPHENE see P050
	Iodrin see P050
P064	Isovaleric acid, methyl ester
	KILOSEB see P020
	KOP-THIODAN see P050
	KWIK KIL see P108
	KWIKSAN see P092
	KUMADER see P001
	KYFARIN see P001
	LEYTOSAN see P092
	LIQUIPHENE see P092

Hazardous Waste No.	Substance
	MALIX see P050
	MAREVAN see P001
	MAR FRIN see P001
	MARTIN D MAR FRIN see P001
	MAVERAN see P001
	MEGATOX see P005
P065	Mercury fulminate
	MERSOLITE see P062
	METACID 50 see P071
	METAFOS see P071
	METAPHOR see P071
	METAPHOS see P071
	METASOL 30 see P062
P066	Meprobamate
P067	2-Methylamidine
	METHYLE 605 see P071
P068	Methyl hydrazine
	Methyl isocyanate see P064
P069	2-Methylfurfural
P070	2-Methyl-2-(methylthio)propanaldehyde- (methylcarbonyl) oxime
	METHYL NIRON see P042
P071	Methyl parathion
	METRON see P071
	MOLE DEATH see P108
	MOUSE NOTS see P108
	MOUSE RID see P108
	MOUSE-TOX see P108
	MUSCIMOL see P007
P072	1-Naphthyl-2-thiourea
P073	Nickel carbonyl
P074	Nickel cyanide
P075	Nicotine and salts
P076	Nitric oxide
P077	p-Nitroaniline
P078	Nitrogen dioxide
P079	Nitrogen peroxide
P080	Nitrogen tetroxide
P081	Nitroethylene (R)
P082	N-Nitrosodimethylamine
P083	N-Nitrosodiphenylamine
P084	N-Nitrosodimethylphenylamine
	NYLUMERATE see P082
	OCTALOX see P037
P085	Octamethylpyrophosphoramide
	OCTAN see P092
P086	Olef alcohol condensed with 2 moles ethylene oxide
	OMPA see P085
	OMPAIDE see P085
	OMPAK see P085
P087	Osmium tetroxide
P088	7-Oxalocyclo(2,2,1)heptane-2,3-dicarboxylic acid
	PANIVARIN see P001
	PANORAM D-31 see P037
	PANTHERINE see P007
	PANWARIN see P001
P089	Parathion
	PCP see P090
	PENNCAP M see P071
P090	PENOXYL CARBON N see P048
	Pentachlorophenol
	Pentachlorophenolate see P090
	PENTA-KILL see P090
	PENTASOL see P090
	PENWAR see P090
	PERMIDE see P090
	PERMACUARD see P090
	PERMATOX see P090
	PERMITE see P090
	PERTOX see P090
	PESTOX III see P085
	PHENMAD see P092
	PHENOTAN see P092
P091	Phenyl dichloroarsine
	Phenyl mercaptan see P014
P092	Phenylmercury acetate
P093	N-Phenylthiourea
	PHILIPS 1881 see P008
	PHIX see P092
P094	Phorate
P095	Phosgene
P096	Phosphine
P097	Phosphorothioic acid, O,O-dimethyl ester, O-ethyl with N,N-dimethyl benzene sulfonamide
	Phosphorothioic acid, O,O-dimethyl-O-(p-nitro- phenyl) ester see P071
	PED PIPER MOUSE SEED see P108
P098	Potassium cyanide
P099	Potassium silver cyanide
	PRIMERGE see P029
P100	1,2-Propenediol
	Propargyl alcohol see P102
P101	Propionitrile

Hazardous Waste No.	Substance
P102	2-Propynyl-1-ol
	PROTHROMADIN see P001
	QUICKSAM see P092
	QUINTOX see P017
	RAT AND MICE BAIT see P001
	RAT-B-WAY see P001
	RAT-B-GON see P001
	RAT-D-GON #2 see P001
	RAT-GUARD see P001
	RAT-KILL see P001
	RAT-MIX see P001
	RATS-NO MORE see P001
	RAT-OLA see P001
	RATOREX see P001
	RATTUHAL see P001
	RAT-TROL see P001
	RO DETOL see P001
	RO-DE-1 see P108
	ROEX see P001
	ROUGH & READY MOUSE MIX see P001
	SANASEED see P108
	SANTOPRITE see P090
	SANTOPHEN see P090
	SANTOPHEN 20 see P090
	SCHRADAN see P085
P103	Selenious acid
P104	Silver cyanide
	SMITE see P105
	SPARC see P020
	SPOR-C see P092
	SPRAY-TROL BRAND RODENT TROL see P001
	SPURGE see P020
P105	Sodium azide
	Sodium cyanide see P001
P106	Sodium cyanide
	Sodium fluoroborate see P056
	SODIUM WARFARIN see P001
	SOLFARIN see P001
	SOLFOBLACK BB see P048
	SOLFOBLACK 59 see P048
P107	SrOxide
P108	Styrene and salts
	SUBTEX see P020
	SYSTEM see P095
	TAG FUNGICIDE see P092
	TEYWAISA see P071
	TEMIK see P070
	TEMIK see P070
	TERMIN TROL see P090
P109	Tetraethylthiopyrophosphate
P110	Tetraethyl lead
P111	Tetraethylthiopyrophosphate
P112	Tetraethylthiopyrophosphate
	Tetraethylthiopyrophosphate
	TETROSULFUR BLACK PB see P048
	TETROSULFUR PBR see P048
P113	Thalic acid
	Thallium peroxide see P113
P114	Thallium selenide
P115	Thallium (I) sulfate
	THIFOR see P092
	THIMUL see P092
	THIODAN see P050
	THIOFON see P050
	THIOFON see P050
	THIOFON see P050
	THIOFON see P050
	THIOFON see P050
P116	Thionitrite see P071
	Thionitrite see P071
P117	Thionitrite see P050
	Thionitrite see P050
P118	THOMPSON'S WOOD FIRE see P090
	TIOVEL see P050
P119	Tinonitrite see P050
	TWIN LIGHT RAT AWAY see P001
	USAF RH-8 see P048
	USAF EX-4870 see P001
P119	Vanadic acid, ammonium salt
P120	Vanadium pentoxide
	VDFATOX see P071
	WANADU see P120
	WARFARIN see P001
	WARFARIN SODIUM see P001
	WARFARIN see P001
	WOFOTOX see P112
	WOFOTOX see P051
	WOFOTOX see P051
	WOFOTOX see P051
P121	Zinc cyanide
P122	Zinc phosphide (R)
	ZOCCUMARIN see P091

Toxic Waste

Hazardous Waste No	Substance
U001	AAF see U005
U002	Acetaldehyde
U003	Acetone (I)
U004	Acetone (II)
U005	Acetophenone
U006	2-Acetylaminofluorene
U007	Acetyl chloride (C, T)
U008	Acrylamide
U009	Acetylene tetrachloride see U209
U010	Acetylene trichloride see U226
U011	Acrylonitrile
U012	AEROTHENE TT see U226
U013	3-Amino-5-(p-acetamidophenyl)-1H-1,2,4-triazole, hydrate see U011
U014	8-Amino-1,1a,2,8a-tetrahydro-8-(pyridin-2-yl)-5-methoxy-5-methylcarbazole, azine(2,3,4) pyrazole(1,2-a) indole-4, 7-dione (ester)
U015	Aniline
U016	Aniline (I)
U017	Asbestos
U018	Auramine
U019	Azobenzene
U020	Benzaldehyde
U021	Benzal chloride
U022	Benzal chloride (C, R)
U023	Benzaldehyde
U024	Benzaldehyde (C, R, T)
U025	Benzaldehyde (C, R, T)
U026	Benzaldehyde (C, R, T)
U027	Benzaldehyde (C, R, T)
U028	Benzaldehyde (C, R, T)
U029	Benzaldehyde (C, R, T)
U030	Benzaldehyde (C, R, T)
U031	Benzaldehyde (C, R, T)
U032	Benzaldehyde (C, R, T)
U033	Benzaldehyde (C, R, T)
U034	Benzaldehyde (C, R, T)
U035	Benzaldehyde (C, R, T)
U036	Benzaldehyde (C, R, T)
U037	Benzaldehyde (C, R, T)
U038	Benzaldehyde (C, R, T)
U039	Benzaldehyde (C, R, T)
U040	Benzaldehyde (C, R, T)
U041	Benzaldehyde (C, R, T)
U042	Benzaldehyde (C, R, T)
U043	Benzaldehyde (C, R, T)
U044	Benzaldehyde (C, R, T)
U045	Benzaldehyde (C, R, T)
U046	Benzaldehyde (C, R, T)
U047	Benzaldehyde (C, R, T)
U048	Benzaldehyde (C, R, T)
U049	Benzaldehyde (C, R, T)
U050	Benzaldehyde (C, R, T)
U051	Benzaldehyde (C, R, T)
U052	Benzaldehyde (C, R, T)
U053	Benzaldehyde (C, R, T)
U054	Benzaldehyde (C, R, T)
U055	Benzaldehyde (C, R, T)
U056	Benzaldehyde (C, R, T)
U057	Benzaldehyde (C, R, T)
U058	Benzaldehyde (C, R, T)
U059	Benzaldehyde (C, R, T)
U060	Benzaldehyde (C, R, T)
U061	Benzaldehyde (C, R, T)
U062	Benzaldehyde (C, R, T)
U063	Benzaldehyde (C, R, T)
U064	Benzaldehyde (C, R, T)
U065	Benzaldehyde (C, R, T)
U066	Benzaldehyde (C, R, T)
U067	Benzaldehyde (C, R, T)

Hazardous Waste No	Substance
U068	Benzaldehyde (C, R, T)
U069	Benzaldehyde (C, R, T)
U070	Benzaldehyde (C, R, T)
U071	Benzaldehyde (C, R, T)
U072	Benzaldehyde (C, R, T)
U073	Benzaldehyde (C, R, T)
U074	Benzaldehyde (C, R, T)
U075	Benzaldehyde (C, R, T)
U076	Benzaldehyde (C, R, T)
U077	Benzaldehyde (C, R, T)
U078	Benzaldehyde (C, R, T)
U079	Benzaldehyde (C, R, T)
U080	Benzaldehyde (C, R, T)
U081	Benzaldehyde (C, R, T)
U082	Benzaldehyde (C, R, T)
U083	Benzaldehyde (C, R, T)
U084	Benzaldehyde (C, R, T)
U085	Benzaldehyde (C, R, T)
U086	Benzaldehyde (C, R, T)
U087	Benzaldehyde (C, R, T)
U088	Benzaldehyde (C, R, T)
U089	Benzaldehyde (C, R, T)
U090	Benzaldehyde (C, R, T)
U091	Benzaldehyde (C, R, T)
U092	Benzaldehyde (C, R, T)
U093	Benzaldehyde (C, R, T)
U094	Benzaldehyde (C, R, T)
U095	Benzaldehyde (C, R, T)
U096	Benzaldehyde (C, R, T)
U097	Benzaldehyde (C, R, T)
U098	Benzaldehyde (C, R, T)
U099	Benzaldehyde (C, R, T)
U100	Benzaldehyde (C, R, T)
U101	Benzaldehyde (C, R, T)
U102	Benzaldehyde (C, R, T)
U103	Benzaldehyde (C, R, T)
U104	Benzaldehyde (C, R, T)
U105	Benzaldehyde (C, R, T)
U106	Benzaldehyde (C, R, T)
U107	Benzaldehyde (C, R, T)
U108	Benzaldehyde (C, R, T)
U109	Benzaldehyde (C, R, T)
U110	Benzaldehyde (C, R, T)
U111	Benzaldehyde (C, R, T)
U112	Benzaldehyde (C, R, T)
U113	Benzaldehyde (C, R, T)
U114	Benzaldehyde (C, R, T)
U115	Benzaldehyde (C, R, T)
U116	Benzaldehyde (C, R, T)
U117	Benzaldehyde (C, R, T)
U118	Benzaldehyde (C, R, T)
U119	Benzaldehyde (C, R, T)
U120	Benzaldehyde (C, R, T)
U121	Benzaldehyde (C, R, T)
U122	Benzaldehyde (C, R, T)
U123	Benzaldehyde (C, R, T)
U124	Benzaldehyde (C, R, T)
U125	Benzaldehyde (C, R, T)
U126	Benzaldehyde (C, R, T)
U127	Benzaldehyde (C, R, T)
U128	Benzaldehyde (C, R, T)
U129	Benzaldehyde (C, R, T)
U130	Benzaldehyde (C, R, T)
U131	Benzaldehyde (C, R, T)
U132	Benzaldehyde (C, R, T)
U133	Benzaldehyde (C, R, T)
U134	Benzaldehyde (C, R, T)
U135	Benzaldehyde (C, R, T)
U136	Benzaldehyde (C, R, T)
U137	Benzaldehyde (C, R, T)
U138	Benzaldehyde (C, R, T)
U139	Benzaldehyde (C, R, T)
U140	Benzaldehyde (C, R, T)

Toxic Waste - Continued

Hazardous Waste No	Substance
U141	Isosaltol
U142	Kapone
U143	Laurocarpine
U144	Lead acetate
U145	Lead phosphate
U146	Lead subacetate
U147	Maleic anhydride
U148	Maleic hydrazide
U149	Malononitrile
	MEK Peroxide see U180
U150	Merphalan
U151	Mercury
U152	Methacrylonitrile
U153	Methanethiol
U154	Methanol
U155	Methacrylene
	Methyl alcohol see U154
U156	Methyl chloroformate
	Methyl chloroform see U228
U157	3-Methylcholanthrene
	Methyl chloroformate see U156
U158	4-Methylstyrene (2-chloroaniline)
U159	Methyl ethyl ketone (MEK) (R,T)
U160	Methyl ethyl ketone peroxide (R)
	Methyl oxide see U138
U161	Methyl isobutyl ketone
U162	Methyl methacrylate (R,T)
U163	N-Methyl-N-nitro-N-nitrosoguanidine
U164	Methylthiourea
	Mitomycin C see U010
U165	Naphthalene
U166	1,4-Naphthoquinone
U167	1-Naphthylamine
U168	2-Naphthylamine
U169	Nitrobenzene (R,T)
	Nitrobenzyl see U168
U170	4-Nitrophenol
U171	2-Nitropropane (R)
U172	N-Nitrosodimethylamine
U173	N-Nitrosodimethylaniline
U174	N-Nitrosodimethylamine
U175	N-Nitrosodimethylamine
U176	N-Nitrosodimethylamine
U177	N-Nitrosodimethylamine
U178	N-Nitrosodimethylamine
U179	N-Nitrosodimethylamine
U180	N-Nitrosodimethylamine
U181	5-Nitro-2-toluidine
U182	Paraldehyde
	PCNB see U185
U183	Pentachlorobenzene
U184	Pentachlorobenzene
U185	Pentachlorobenzene
U186	1,3-Pentachlorobenzene (R)
	Perc see U210
	Perchloroethylene see U210
U187	Phenacetin
U188	Phenol
U189	Phosphorous sulfide (R)
U190	Phthalic anhydride

Hazardous Waste No	Substance
U191	2-Picoline
U192	Propylene
U193	1,3-Propylene sulfone
U194	n-Propylamine (R)
U195	Pyridine
U197	Quinones
U200	Resorcinol
U201	Resorcinol
U202	Saccharin
U203	Saltol
U204	Selenious acid
U205	Selenium sulfide (R,T)
	Shlex see U233
U206	Styrene
	2,4,5-T see U232
U207	1,2,4,5-Tetrachlorobenzene
U208	1,1,1,2-Tetrachloroethane
U209	1,1,2,2-Tetrachloroethane
U210	Tetrachloroethylene
	Tetrachloroethylene see U210
U211	Tetrachloroethylene
U212	2,3,4,5-Tetrachlorobenzene
U213	Tetrahydrofuran (R)
U214	Thallium (II) acetate
U215	Thallium (II) carbonate
U216	Thallium (II) chloride
U217	Thallium (II) nitrate
U218	Thioacetamide
U219	Thiourea
U220	Toluene
U221	Toluenesulfonamide
U222	p-Toluidine hydrochloride
U223	Toluene dithiocarbamate
U224	Toluidine
	2,4,5-TP see U233
U225	Tribromomethane
U226	1,1,1-Trichloroethane
U227	1,1,2-Trichloroethane
U228	Trichloroethylene
	Trichloroethylene see U228
U229	Trichloroethylene
U230	2,4,5-Trichlorophenol
U231	2,4,6-Trichlorophenol
U232	2,4,5-Trichlorophenoxyacetic acid
U233	2,4,5-Trichlorophenoxypropionic acid, alpha, alpha, alpha-Trichlorobenzene see U023
	TRI-CLENE see U228
U234	Trinitrobenzene (R,T)
U235	Tris(2,3-dibromopropyl) phosphate
U236	Trypan blue
U237	Ureol mustard
U238	Urethane
	Vinyl chloride see U043
	Vinylidene chloride see U078
U239	Xylene